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EARTHQUAKE RESISTANT SUBMARINE DRYDOCK BLOCK SYSTEM DESIGN

by

LIEUTENANT JAMES KENNETH LUCHS, Jr. U.S. NAVY

B.S. Mechanical Engineering  
Cornell University (1979)

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LIEUTENANT JAMES KENNETH LUCHS, Jr. U.S. NAVY

Submitted to the Department of Ocean Engineering in partial fulfillment of the requirements for the degrees of Naval Engineer and Master of Science in Mechanical Engineering

## ABSTRACT

→ This thesis develops a 3-degree →

A three degree of freedom submarine drydock blocking system computer aided design package, is developed. Differential equations of motion are developed to take into account high blocking systems, wale shores, and side block cap angles. The computer program is verified by a case study involving the earthquake sliding failure of the *USS Leahy* (CG-16). A parametric study is conducted to determine the effects of wale shores, isolators, and block stiffness and geometry variations on system survivability. The effects of using earthquake acceleration time histories with differing frequency spectrums on system survivability is studied.

None of eleven submarine drydock blocking systems studied survive to dry dock failure (0.26 g's) or even meet the Navy's current 0.2 g survival requirement. This shows that current U.S. Navy submarine drydock blocking systems are inadequate to survive expected earthquakes. Two design solutions are found that meet the dry dock failure requirements. The low stiffness solution uses dynamic isolators and rubber caps, and the high stiffness solution uses wale shores and rubber caps. The wale shore solution virtually prevents the submarine from moving horizontally relative to the dock floor. The isolator solution allows relatively large horizontal displacements to occur. Using the wale shore solution, the submarine experiences forces which are an order of magnitude higher than those seen by the isolator solution.

Both ~~of the~~ design solutions can be constructed; however, there are cost and production interference concerns. Considering the almost certain occurrence of a major earthquake in the proximity of a U.S. Naval shipyard where submarines can be drydocked within the next 20 years, the expeditious incorporation of one of these design solutions into U.S. Navy drydocking standards is strongly recommended.

THESIS SUPERVISOR: Dale G. Karr, Ph.D.

TITLE: Associate Professor of Ocean Engineering

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## BIOGRAPHICAL NOTE

The author graduated from Cornell University in 1979 with a Bachelor of Science degree in Mechanical Engineering. He received his commission in the United States Navy through the NROTC program at Cornell. After a few Navy schools he joined the precommissioning crew of the USS Stephen W. Groves (FFG-29) in 1981. He served aboard for three years as Damage Control Assistant, Main Propulsion Assistant and Ordnance Officer. In 1984 he transferred to Engineering Duty and served as a Ship Repair Officer at SUPSHIP Jacksonville. He entered the XIII A program at MIT in June 1985.



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## CHAPTER 1

### INTRODUCTION

#### 1.0 Description of Earthquake Threat to Submarine Drydock Blocking Systems

U.S. Naval shipyards where submarines are drydocked are located in regions of the United States where significant earthquakes are known to occur. These earthquakes produce tremendous forces and ground displacements which seriously threaten the safety of drydocked submarines. They usually occur without any warning, and there is presently no reliable means of predicting their occurrence. Therefore, submarine drydock blocking systems must be designed to resist expected earthquake excitation.

Hepburn [1] described in detail both the nature of the seismic threat to submarines drydocked in U.S. Naval shipyards, and the drydock blocking systems currently in use there. Graving docks at these shipyards are currently designed to withstand earthquake accelerations up to 0.26 g's. Previous research by Sigman [2] and Karr [3] using linear elastic material three degree of freedom models showed that submarine drydock blocking systems would fail due to side block liftoff at accelerations significantly lower than the 0.2 g level required by current Navy drydocking standards [4].

Hepburn's [1] thesis confirmed these results using a bilinear material model for wood which more closely represents its actual behavior. Using this bilinear wood model, it was determined that the submarine drydock blocking systems would fail by side block liftoff at even lower accelerations. Clearly current U.S. Navy submarine drydock blocking systems are inadequate to meet the earthquake threat.

### 1.1 Summary of Bilinear Material Results

Natural rubber and dynamic isolators were analyzed by Hepburn [1] using bilinear models to determine their potential for increasing system survivability. The rubber was used as a substitute for the Douglas fir soft cap, and the dynamic isolators were used as a substitute for the oak (hard wood) layer of the blocking systems. It was determined that significant increases in survivability occur when rubber and dynamic isolators are incorporated in the blocking systems. Rubber caps and isolators either singly or in combination are very attractive potential solutions to the submarine drydock blocking systems' survivability problem.

This thesis uses the three degree of freedom analysis model previously developed by Sigman [2] and Karr [3] with the bilinear material models developed by Hepburn [1] to design earthquake resistant submarine drydock blocking systems. The

use of natural rubber, dynamic isolators, wale shores, blocking system stiffness, and geometry variations is studied.

## 1.2 Thesis Outline

Chapter 2 describes improvements made to the three degree of freedom computer program (3DOFRUB) developed jointly by Luchs and Hepburn. The development of a computer aided design package using this program as the core is described. Significant modifications include the use of horizontal and vertical accelerations input and force and displacement output files, and development of miscellaneous support programs.

Chapter 3 describes the changes made in the equations of motion to include the effects of cap angle and side block height. This chapter also describes the effect of adding wale shores to the blocking system. In addition, the side block wedge effect on the sliding failure mode is developed.

The earthquake effects on the USS Leahy (CG-16) drydock blocking system at Long Beach Naval Shipyard is described in a case study in chapter 4. The results of this study are used as a verification of the three degree of freedom drydock blocking system model and computer program. In chapter 5, a parametric study on the effect of wale shores, dynamic isolators, and stiffness and block geometry variations is conducted.



The site specific earthquake effects on drydock blocking system designs is analyzed in chapter 6. A low stiffness dynamic isolator based drydock blocking design is developed in chapter 7. Similarly, in chapter 8 a high stiffness wale shore based drydock blocking design is developed. Finally, a comparison of results, conclusions, and recommendations for further study is included in chapter 9.

## CHAPTER 2

### DEVELOPMENT OF THE THREE DEGREE OF FREEDOM EARTHQUAKE RESISTANT DRYDOCK BLOCKING DESIGN PACKAGE

#### 2.0 Three Degree of Freedom Computer Program Background

The computer program used to analyze the submarine drydock blocking systems in this thesis was developed jointly with Hepburn [1] and is based on the program developed by Sigman [2]. Many significant modifications are made to Sigman's program and several support programs are written to improve the usefulness of this program as a design tool. The two subroutines developed to model bilinear material properties, "BILINALL" and "RUBBER", are described in detail by Hepburn [1].

The significant modifications made in this thesis include the addition of horizontal and vertical acceleration inputs, force and displacement outputs, and changes to the equations of motion to include more complex geometry. The geometry changes took into account the effects of side block height, cap angle, and the inclusion of wale shores. In addition, the side block wedge effect on the sliding failure mode is included in the program.

The main program, "3DOFRUB", inputs submarine drydock blocking system parameters then calculates the system's modal masses, stiffnesses, damping coefficients, and natural frequencies. The horizontal acceleration time history (and vertical if applicable) are input using the "ACCLINPT" subroutine. The main loop of the program solves the equations of motion using the Fourth Order Runge-Kutta numerical method. The blocking material stiffnesses are recalculated each time step using the appropriate subroutines. At each time step, keel and side block forces are calculated, and the system is tested for failure.

The program begins by using 100 percent of the amplitude of the input acceleration time history. It carries out repeated loops through the whole history each time decreasing the input acceleration. This continues until the system survives a complete loop through the time history. Force and displacement data files as chosen by the user are created using subroutine "RESPALL" for use in plotting system response. The main program, "3DOFRUB", and all four subroutine listings are included in Appendix 1. A sample input data file and output file are also included in this appendix.

## 2.1 Horizontal and Vertical Acceleration Input

Sigman's program only allowed the input of horizontal earthquake acceleration time histories. Vertical accelerations are input to the program by multiplying the horizontal accelerations by a selected constant. The resulting vertical acceleration is, therefore, identical in wave form with the horizontal acceleration which is not always the case for actual earthquakes. A better way of handling vertical accelerations is to use actual vertical acceleration time histories. The "ACCLINPT" subroutine allows both horizontal and vertical acceleration time histories to be read independently.

The "ACCLINPT" subroutine asks the user for the horizontal acceleration file name and then reads the data into an array. The user is then asked if a vertical acceleration file will be used. If the user chooses to use one, its data is read into a different array. If the user declines to use a vertical acceleration file, the user is asked to provide the vertical to horizontal acceleration ratio. Each horizontal acceleration data point is then multiplied by this ratio to create a vertical acceleration data array.

The subroutine then checks to make sure that if horizontal and vertical acceleration inputs are used, both the inputs are from the same earthquake with the same time step.

Finally, "ACCLINPT" provides the main program, "3DOFRUB", with the earthquake name, the horizontal and vertical earthquake component names, and the acceleration time step used.

## 2.2 Force and Displacement Output

In order to display the response of the three degree of freedom system, it is essential to create force and displacement output data files. Sigman's [2] computer program included a computer operating system dependent plotting routine. In order to develop a useful and easily portable software package, force and displacement response data is output in ASCII files. This allows the user the option of using a wide variety of plotting programs to display the response data. The main program can then be run on any system, including personal computers, that has a FORTRAN compiler.

The main program, "3DOFRUB", asks the user if response and displacement output files are desired. If these files are desired, the user can chose which of five force components should be output. These force components are (1) keel horizontal force, (2) side block horizontal force, (3) left side block vertical force, (4) right side block vertical force, and (5) keel block vertical force.

The main program calculates the appropriate force and displacements. The program selects the correct displacements corresponding to the chosen force then captures them in arrays. For example, if left side block vertical force is selected, the displacement, YPRIME, is captured. YPRIME includes the vertical displacement of the keel, rotation about the keel times the lever arm to the left side block, and the static deflection of the side block due to submarine weight.

"RESPALL" is the subroutine which creates force and displacement output files. This subroutine asks the user for x displacement, y displacement, rotation, and force output file names. It then writes the force and displacement arrays captured by the main program to these files. The program only creates output data files for an earthquake magnitude that the system survives (where no failures occur). These output files are formatted such that they are directly usable by LOTUS 123 and other graphics programs.

### 2.3 Development of Miscellaneous Support Programs

Several support programs are developed to produce acceleration time history data files usable by "3DOFRUB". The first program, "V2READs", based on a program provided by Lew 1988 [5], creates three separate single column format acceleration data files. The input for this FORTRAN program is the standard format magnetic media data file containing

three complete earthquake records each provided by the National Geophysical Data Center, Boulder, Colorado [6].

The second program, "ACCELMOD", modifies an acceleration data file in single column format by adding a new data point found by linear interpolation between each original data point. This is necessary in some cases (e.g. the 1 October 1987 Whittier, California earthquake) to improve the accuracy of the numerical computational scheme. The Whittier earthquake was recorded with a 0.02 second time step. The "3DOFRUB" program produces the best results if the time step is 0.01 seconds or less.

The third computer program, "DATINNEW", written in BASIC inputs acceleration data from ASCII data files in either single or multiple column format and modifies it in several ways. First, if desired the program adds character string labels to the first three lines of the output data file. These labels are the name of the earthquake, the acceleration component name, and the acceleration time step. These labels are required in order for the output file to be used directly by "3DOFRUB".

"DATINNEW" allows the user to produce an output data file of any length up to the maximum number of entries in the input data file. The program also allows the user to multiply each data point by a desired constant to produce earthquake time

histories of varying magnitudes. The program gives the user the option of having the output data file be in units of inches per second squared or centimeters per second squared. "3DOFRUB" requires centimeters per second squared data input. "DATINNEW" removes gaps in data files produced by programs such as LOTUS 123. The output of the program is an ASCII data file in single column format.

Another BASIC program, "MAKERUB", is developed to create submarine and blocking system data input files for "3DOFRUB". This program is written based on a BASIC program written by Paz (1986) [7]. This computer program allows the user to prepare new data files or modify existing data files. The program is labeled in detail and identifies all submarine and blocking system data input file entries including their units as used by "3DOFRUB". The program is versatile in that data files can be moved, recalled, and modified quickly and easily.

"MAKERUB" prompts the user for each data entry by description, units, and variable name. The program then creates data files in the exact format required by "3DOFRUB" without the user having to adjust anything. One important feature of this program is that it labels the data files with identifying information so when the data files are displayed the user can see all pertinent information as text. The four programs described in this section are included in Appendix (2).



## CHAPTER 3

### GEOMETRICAL IMPROVEMENTS TO THE THREE DEGREE OF FREEDOM MODEL AND COMPUTER PROGRAM

#### 3.0 Geometrical Improvements to the Three Degree of Freedom Equations of Motion

The three degree of freedom model of the submarine drydock blocking system at rest as developed by Sigman (1986) [2] and used by Hepburn [1] is the system used as a baseline for this thesis. Figure (3.1) is a two dimensional representation of the submarine and dry dock with the keel and side block piers modeled as horizontal and vertical springs and dashpots.

This figure differs from Sigman's model in several respects. First, wale shores, modeled as horizontal springs and dashpots, at a distance AAA from the keel are added. Second, the height of the side blocks above the keel baseline and the resulting angle alpha between the baseline and a line through the keel and side block point of contact is shown and taken into account in the equations of motion.

The point CG1 is the initial location of the center of gravity of the submarine. The point K is the initial location of the keel of the submarine. The point K', insert figure (3.2), is the location of the keel after horizontal and vertical translation has occurred. Rotation occurs about this point. KG is the distance from the keel to the center of

gravity. The distance  $b_r$  is the transverse distance between the center of the caps of the port and starboard side blocks. The horizontal, vertical, and wale shore spring constants are as designated in the figure.

The system is excited by horizontal and vertical dry dock accelerations  $\ddot{x}_g$  and  $\ddot{y}_g$  respectively. The entire dry dock and submarine system moves relative to a fixed reference frame. The excited system is shown in figure (3.2). The system of equations are expressed in terms of motion of the submarine relative to the dry dock.

The point CG2 in figure (3.2) is the location of the center of gravity of the submarine relative to the fixed reference frame after horizontal displacement  $u$  and vertical displacement  $v$ . The point CG3 is the location of the submarine's center of gravity after the additional absolute rotation  $\theta$ . The insert at the bottom of figure (3.2) is a close up of the keel area of the submarine during this motion. The displacements illustrated are described as follows:

The relative horizontal displacement coordinate  $x$  is the displacement of the submarine keel with respect to the dry dock. The displacement  $u$  is the position of the keel relative to the fixed reference frame. With ground motion  $x_g$  the following equations hold:

$$x = u - x_0$$

$$u = x + x_0$$

$$\ddot{u} = \ddot{x} + \ddot{x}_0 \quad (3.1)$$

Similarly for vertical translation the following equations hold:

$$y = v - y_0$$

$$v = y + y_0$$

$$\ddot{v} = \ddot{y} + \ddot{y}_0 \quad (3.2)$$

The coupled non-linear three degree of freedom equations describing the system motion as developed by Sigman are as follows:

$$M\ddot{x} + M\overline{KG}\ddot{\theta} + C_{\dot{x}}\dot{x} + C_{\dot{\theta}}\dot{\theta} + (2khs+khk)x = -M\ddot{x}_0 \quad (3.3)$$

$$M\ddot{y} + C_{\dot{y}}\dot{y} + (2kvs+kvk)y = -M\ddot{y}_0 \quad (3.4)$$

$$I_L\ddot{\theta} + M\overline{KG}\ddot{x} - M\overline{KG}\ddot{y} + C_{\dot{\theta}}\dot{\theta} + C_{\dot{x}}\dot{x} + [(br^2/2)kvs - WKG]\theta = -M\overline{KG}\ddot{x}_0 \quad (3.5)$$

[illegible]

FIGURE 3.1

Three Degree of Freedom Submarine  
Drydock Blocking System Model Excited

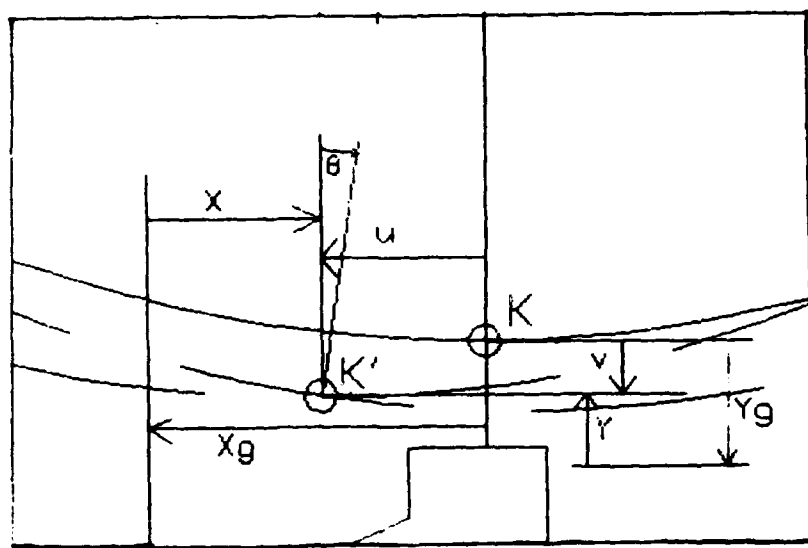
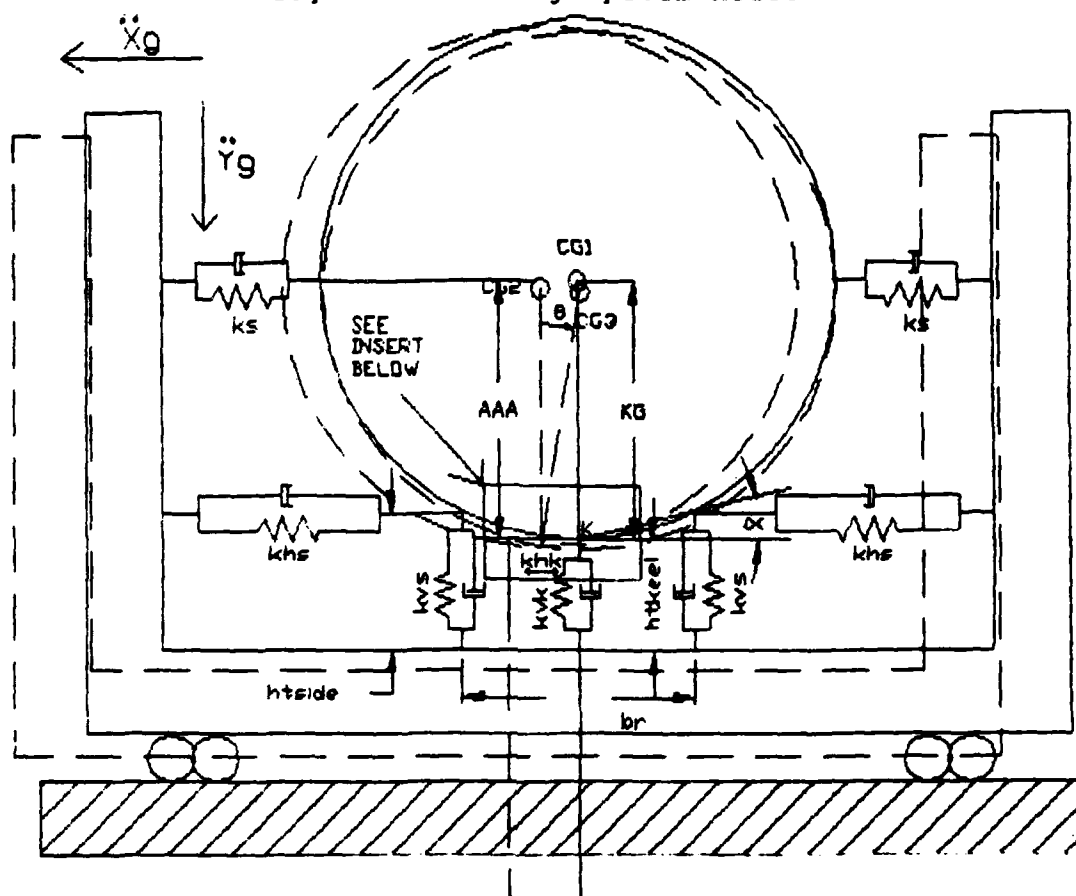


FIGURE 3.2

In equations 3.3 through 3.5,  $M$  is the mass of the submarine,  $I_k$  is the rotational moment of the submarine about the keel, and  $W$  is the weight of the submarine.

Sigman's analysis assumed that the height of the keel blocks was the same as the height of the side blocks. Therefore, the lever arm from the keel to the side block hull point of contact is  $br/2$ . Taking the actual height of the side block into account gives the following expression for this lever arm:

$$LLL = ((ht_{side} - ht_{keel})^2 + (br/2)^2)^{1/2} \quad (3.6)$$

The angle  $\alpha$  is then:

$$\alpha = \sin^{-1}((ht_{side} - ht_{keel})/LLL) \quad (3.7)$$

Figure (3.3) is an illustration of the additional vertical and horizontal displacements of the side block cap due to rotation  $\theta$  of the submarine about the keel. The insert at the bottom of figure (3.3) is a close-up of the side block cap geometry during submarine rotation. Assuming small angle rotation, the displacement of the cap due to rotation is  $L\theta$ . The vertical component of  $L\theta$  is  $R$ . The horizontal component is  $Z$ .  $L$  in the figure is the same as  $LLL$  in equation (3.6).

Vertical and Horizontal Displacements  
of the Side Block Cap Due to Rotation

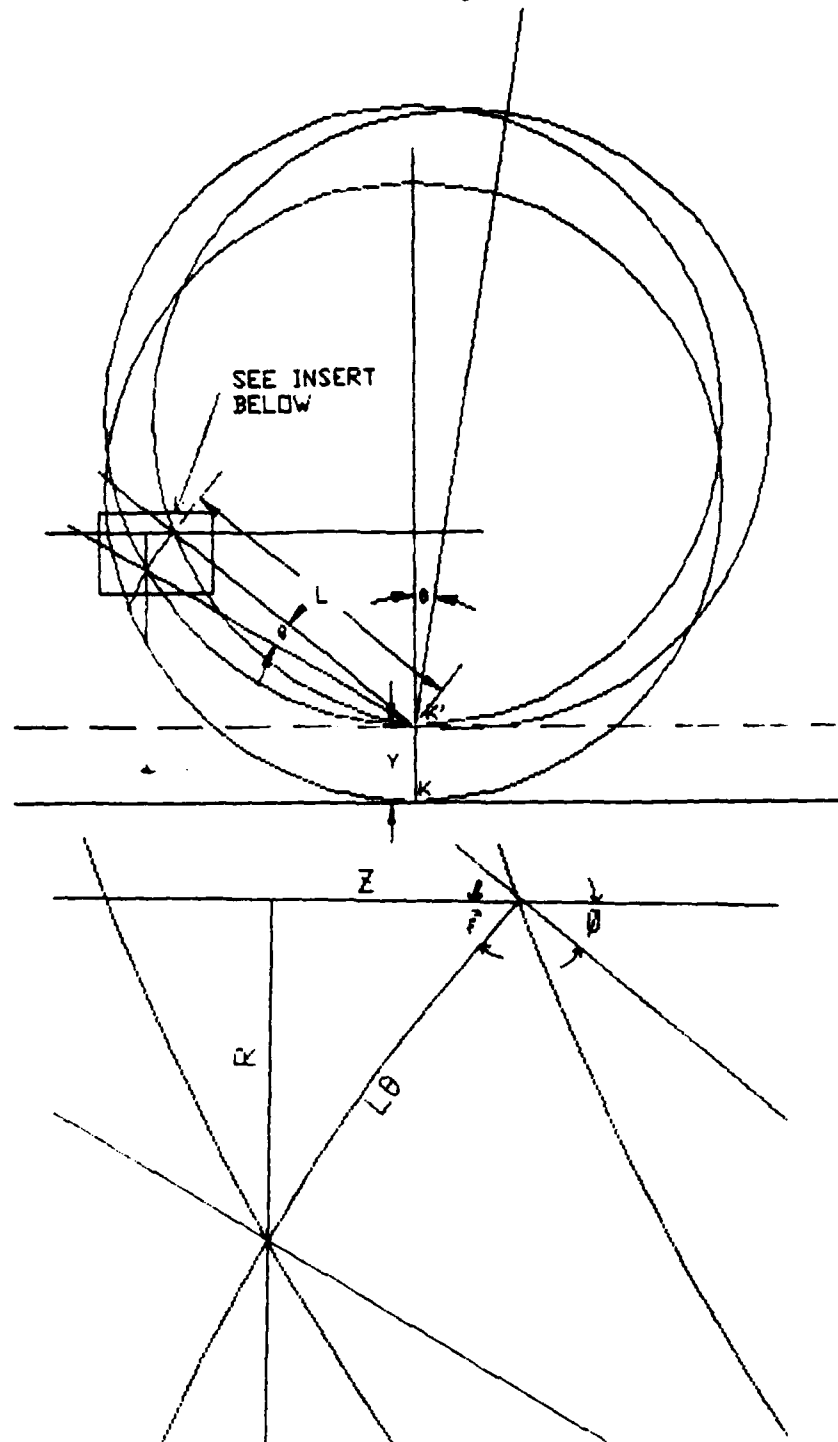


FIGURE 3.3

The expression for R is developed as follows:

$$R = L\theta \sin(\gamma) \quad (3.8)$$

$$\sin(\phi) = (BU + R)/L \quad (3.9a)$$

For small angles of rotation:

$$\sin(\phi) = (BU)/L \quad (3.9b)$$

$$BU = h_{\text{side}} - h_{\text{keel}} \quad (3.10)$$

From figure (3.3):

$$\gamma + 90^\circ + \phi = 180 \quad (3.11)$$

$$\gamma = 90^\circ - \phi \quad (3.12)$$

Combining with equation (3.9b) gives:

$$\gamma = 90^\circ - \sin^{-1}(BU/L) \quad (3.13)$$

Using a trigonometric identity gives:

$$\sin(\gamma) = \cos(\sin^{-1}(BU/L)) \quad (3.14)$$

Substituting in equation (3.7) gives:

$$\sin(\gamma) = \cos(\alpha) \quad (3.15)$$

Therefore:

$$R = L\theta \cos(\alpha) \quad (3.16)$$

In the case where  $BU = 0$  (side block height = keel block height) as was the case in Sigman's analysis equation (3.16) reduces to:

$$R = L\theta \quad (3.17)$$

In this case  $L = br/2$  and therefore:

$$R = (br/2) * \theta \quad (3.18)$$



Similarly:

$$Z = L\theta \cos(\gamma) \quad (3.19)$$

$$Z = L\theta \sin(\alpha) \quad (3.20)$$

In the case where  $BU = 0$  and  $L = br/2$ :

$$Z = L\theta \sin(0) = 0 \quad (3.21)$$

R and Z are used in calculating the horizontal and vertical forces on the side blocks. Without these geometric relationships, the horizontal force exerted on the side blocks of submarines due to rotation is not taken into account. Not including this force is a significant underestimate of the true horizontal forces seen by the side blocks. Including this effect represents an important improvement to Sigman's model.

With these equations incorporated into the "3DOFRUB" computer program, the model is now general enough to take into account the high buildups of surface ships. Even though for submarines, including the geometric side block effects only changes the survivability of the systems by approximately one percent, for ships with higher buildups these effects will be larger.

The total blocking system forces are calculated as follows:

Keel block horizontal force:

$$RR1 = khkb * x \quad (3.22)$$

Right and left side block horizontal force:

$$RR2 = khsb * XPRIME \quad (3.23)$$

$$XPRIME = x + Z \quad (3.24)$$

Left side block vertical force:

$$RR3 = kvsb1 * YPRIME1 \quad (3.25)$$

$$YPRIME1 = -y - R + DELTA \quad (3.26)$$

Right side block vertical force:

$$RR4 = kvsb2 * YPRIME2 \quad (3.27)$$

$$YPRIME2 = -y + R + DELTA \quad (3.28)$$

Keel block vertical force:

$$RR5 = kvkb * YPRIME3 \quad (3.29)$$

$$YPRIME3 = -y + DELTA \quad (3.30)$$

Right and left wale shore horizontal force:

$$RR6 = ks * (x + AAA * \theta) \quad (3.31)$$

The total blocking system moments about the keel are calculated as follows:

Right and left side block horizontal moment:

$$MM1 = RR2*LLL*\sin(\alpha) \quad (3.32)$$

Left side block vertical moment:

$$MM2 = RR3*LLL*\cos(\alpha) \quad (3.33)$$

Right side block vertical moment:

$$MM3 = RR4*LLL*\cos(\alpha) \quad (3.34)$$

Right and left wale shore horizontal moment:

$$MM4 = RR6*AAA \quad (3.35)$$

DELTA is the static deflection of the side and keel blocks due to the submarine's weight. The value of DELTA is calculated in each loop of "3DOFRUB" and depends on the values of the current side block and keel block vertical stiffnesses. All blocking stiffness (e.g. khkb) are those found from appropriate "BILINALL" or "RUBBER" subroutines. If a linear material analysis is selected by the program user, linear material stiffness values are used.

To derive the modified submarine drydock blocking system equations of motion the following procedure is used. First the forces in horizontal direction are summed and equated with the mass times acceleration in that direction. Next, the forces in the vertical direction are summed and equated with

the mass times acceleration in that direction. Finally, the moments are summed about the keel and equated with the rotational inertia times rotational acceleration. After combining terms and simplifying, the modified equations of motion which include wale shore and side block geometric effects are as follows:

$$\begin{aligned} M\ddot{x} + \overline{MKG}\ddot{\theta} + C_{\dot{x}}\dot{x} + C_{\dot{\theta}}\dot{\theta} + (2ks+2khs+khk)x \\ + (2ks*AAA + 2khs*LLL*SIN(\alpha))\theta = -M\ddot{x}_0 \end{aligned} \quad (3.36)$$

$$M\ddot{y} + C_{\dot{y}}\dot{y} + (2kvs+kvk)y = -M\ddot{y}_0 \quad (3.37)$$

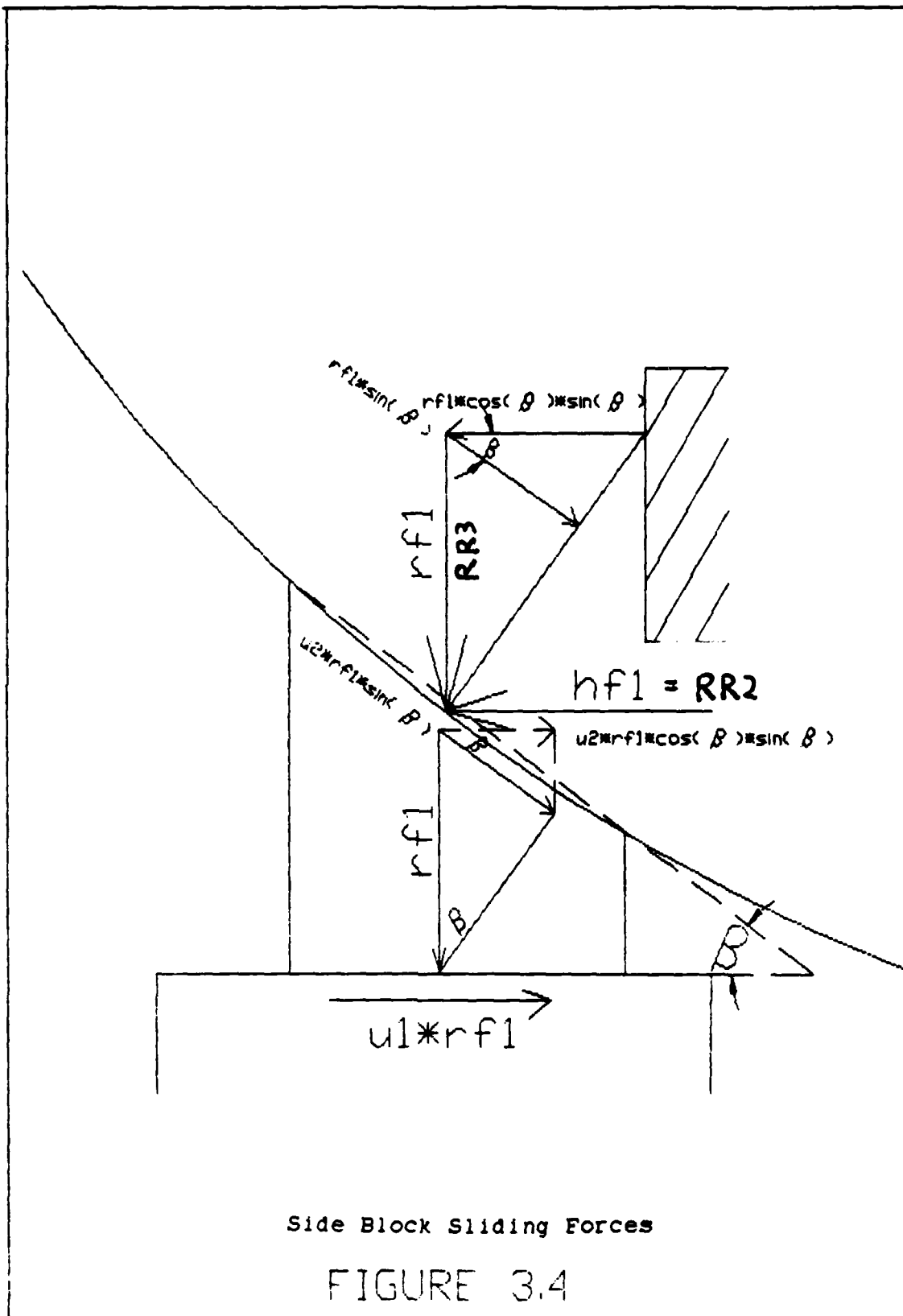
$$\begin{aligned} I_{\dot{\theta}}\ddot{\theta} + \overline{MKG}\ddot{x} - \overline{MKG}\ddot{y}\theta + C_{\dot{\theta}}\dot{\theta} + C_{\dot{x}}\dot{x} \\ + (2ks*AAA + 2khs*LLL*SIN(\alpha))x \\ + [2ks*AAA + 2khs*(LLL*SIN(\alpha))]y \\ + (2*kvs)*(LLL*COS(\alpha))\theta = -\overline{MKG}\ddot{x}_0 \end{aligned} \quad (3.38)$$

The three degree of freedom equations (3.36 - 3.38) are now stiffness as well as inertially coupled. In matrix form, there are now two new elements in the stiffness matrix ( $K_{12} = K_{21}$ ), where  $K_{12} = (2ks*AAA + 2khs*LLL*SIN(\alpha))$ . The first term,  $2ks*AAA$ , is due to wale shores; and the second term,  $2khs*LLL*SIN(\alpha)$ , is due to the effect of system rotation on the side blocks. The stiffness matrix elements  $K_{11}$  and  $K_{22}$  are also modified to include these effects.

### 3.1 Effect of Side Block Cap Angle on System Sliding Failure Mode

All failure modes incorporated in the "3DOFRUB" computer program are the same as those used by Sigman [2] except the slide block sliding failure mode. A more general approach is used to model the side block sliding forces. This allows this program to be used for surface ship block geometries as well as submarines. One additional data input required by the program is the side block cap angle. An average value of side block cap angles, obtained from the submarine docking drawings, is used in this thesis. It is possible to model the failure of the different side blocks along the length of the submarine or ship by running the program separately for each side block right and left set.

Figure (3.4) shows the geometry used in the modeling of the side block cap. The side block cap is modeled as a wedge using a system illustrated in Marks Handbook [8]. Sigman in his analysis did not include the outward force on the side block caused by the vertical forces.



This outward force is caused by the relative rigidity of the ship compared to the side blocks. When a vertical force occurs, it tends to push the block outboard rather than move the ship inboard. The equations describing the forces associated with the side blocks due to this wedge effect and other frictional forces are as follows:

Outboard horizontal forces:

$$hf1 = RR2 \quad (3.39)$$

$$hf2 = RR3 * \cos(\beta) * \sin(\beta) \quad (3.40)$$

Resisting horizontal forces:

$$hf3 = u2 * RR3 * \cos(\beta) * \sin(\beta) \quad (3.41)$$

$$hf4 = u1 * RR3 \quad (3.42)$$

In the figure  $rf1$  is equal to  $RR3$ .  $RR2$  and  $RR3$  are defined in equations 3.23 and 3.25 respectively.

Where:

$\beta$  = the side block cap angle.

$u1$  = is the block on block friction coefficient.

$u2$  = is the hull on block friction coefficient.

If  $rf1$  and  $hf1$  are acting in the direction shown in figure (3.4), "3DOFRUB" flags side block sliding failure if  $hf1 + hf2$  is greater than  $hf3 + hf4$ .

### 3.2 Determination of Blocking System Vertical Static Deflection

Due to the changing stiffness of the side and keel blocks during the earthquake because of their non-linear material properties, the static deflection, DELTA, caused by the submarine weight changes throughout the duration of the earthquake. The accurate calculation of DELTA is essential so that "3DOFRUB" correctly handles permanent set and bilinear material properties. For some cases it is possible for the keel or side blocks to start in the second (plastic) stiffness of the bilinear stiffness model if the submarine weight is great enough.

One assumption is made to simplify the calculation of DELTA. It is assumed that the side block caps would never be elastic when the keel block caps are plastic. The equations for calculating DELTA are as follows:

Elastic case:

$$\text{DELTA} = \text{weight} / (2kvs + kvk) \quad (3.43)$$

Plastic case:

$$\begin{aligned} \text{DELTA} = & \text{YEL3} + (\text{weight} \\ & - (\text{YEL3} * (2kvs + kvk))) / (2kvsp + kvkp) \end{aligned} \quad (3.44)$$

Where:

$$\text{YEL3} = QD4 / (kvk - kvkp) \quad (3.45)$$



QD4 is the keel restoring force, RR5, intercept of the second bilinear stiffness slope. The entire bilinear material model is described by Hepburn [1] in detail.

"3DOFRUB" includes DELTA initialization and recalculation sections. In the initialization section the program first determines whether or not the static deflection has caused the cap material to go plastic or remain elastic. If the material is elastic, then equation (3.43) is utilized to compute DELTA. If the material is plastic, the program uses equation (3.44) to calculate DELTA. If kvk equals kvkp then YEL3 is equal to zero. Then the DELTA equation reduces to the following:

$$\text{DELTA} = \text{weight} / (2\text{kvsp} + \text{kvk}) \quad (3.46)$$

This case occurs when the keel blocks are linear elastic and the side blocks are bilinear rubber. In addition, if either the keel or side blocks are bilinear wood then the elastic case holds initially. For recalculation the same equations are used with the updated stiffness values from the appropriate stiffness subroutines.

## CHAPTER 4

### *USS LEAHY* (CG-16) CASE STUDY

#### 4.0 Background

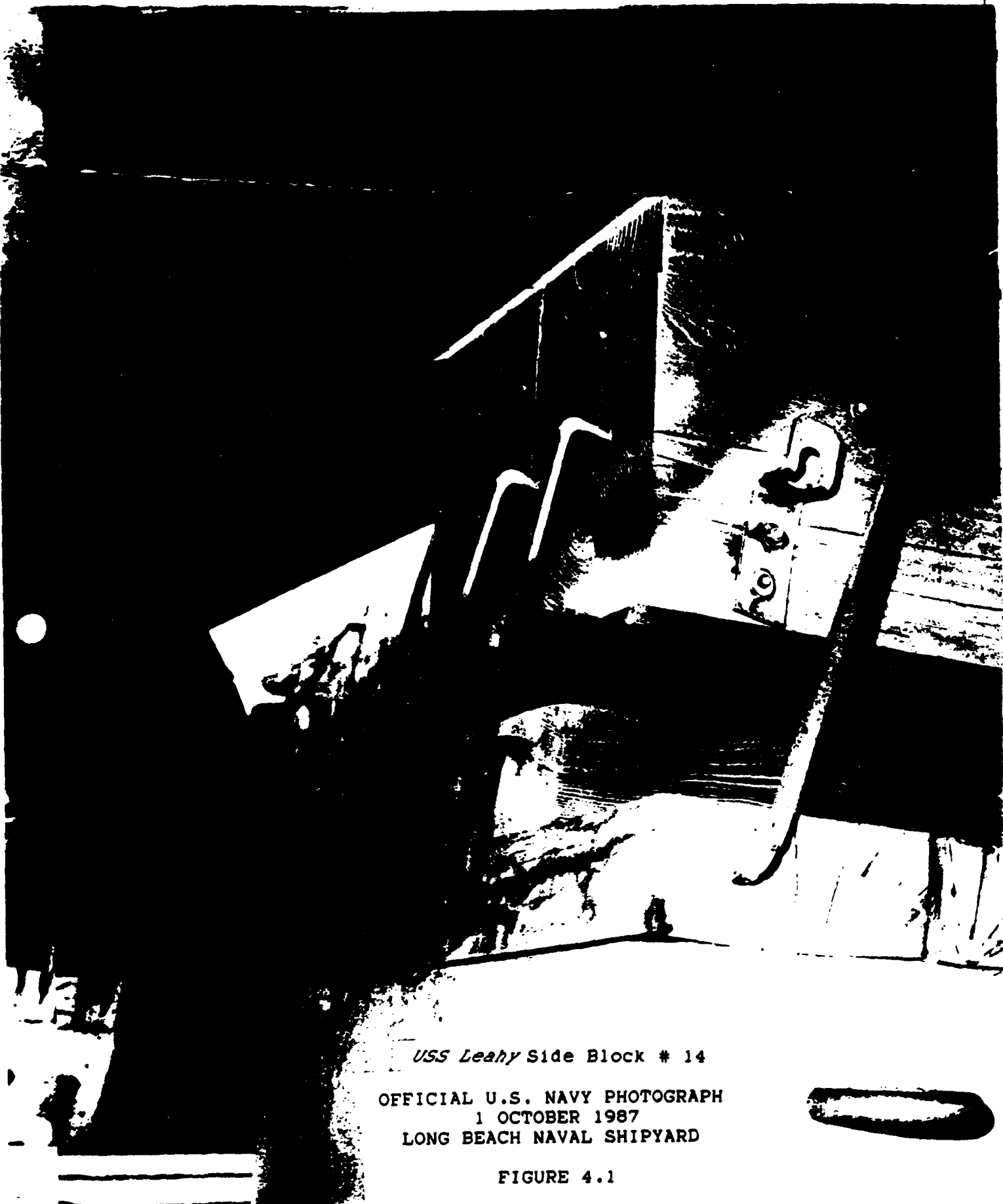
On 1 October 1987, while in graving dock #3 at Long Beach Naval Shipyard (LBNSY), Long Beach, California, the *USS Leahy* (CG-16) experienced an earthquake. The 5.9 magnitude (0.45 g maximum peak acceleration) earthquake had an epicenter located 20 miles to the northeast in Whittier, California [9]. The ship experienced side block sliding and photographs of the drydock blocking system showing the block displacements were taken immediately after the earthquake. In addition, dry docks at LBNSY had been instrumented by accelerographs which recorded the dry dock accelerations (0.05 g peak) seen by the *Leahy* during the earthquake. Because of the recorded displacement and acceleration time histories, the *USS Leahy* was an outstanding case to analyze in order to verify the three degree of freedom model and the "3DOFRUB" computer program.

The October 1st earthquake occurred while this thesis was being researched. Within hours after the earthquake occurred in California, the LBNSY Drydocking Office was contacted and a request for photographs of the blocking system was made. The Docking Officer, Mr. Robert Dixon, reported at that time that the *Leahy's* blocks had shifted outboard during the earthquake,

and four of the side blocks had remained away from the ship after the earthquake was over. Providentially, the ship had recently been sandblasted and painted, and when the earthquake occurred the portions of the hull exposed due to side block sliding were very evident. Therefore, the exact displacements of several of the side blocks following the earthquake was recorded in the photographs taken on October 1st.

Figure (4.1) is a photograph of the # 14 (second most forward) starboard side block. This photograph clearly shows the outboard displacement of the block. It was reported that several of the steel brackets (dogs) holding the block layers together popped out during the earthquake. These brackets were reattached before the photograph was taken.

LBNSY was visited in late October and the *Leahy's* blocking system was examined. The ship was still in dry dock and the area around the displaced blocks had not been repainted. Therefore, the displacements during the earthquake were still evident. These displacements were measured and recorded. There was no evidence of side block or keel block crushing or keel block sliding. There was slight evidence of side block liftoff. This liftoff apparently slightly skewed some of the side blocks so the inboard face of the side blocks was no longer parallel to the keel line. In addition, the new paint that had been applied just before the earthquake was broken between the hull and block interface.



*USS Leahy* Side Block # 14

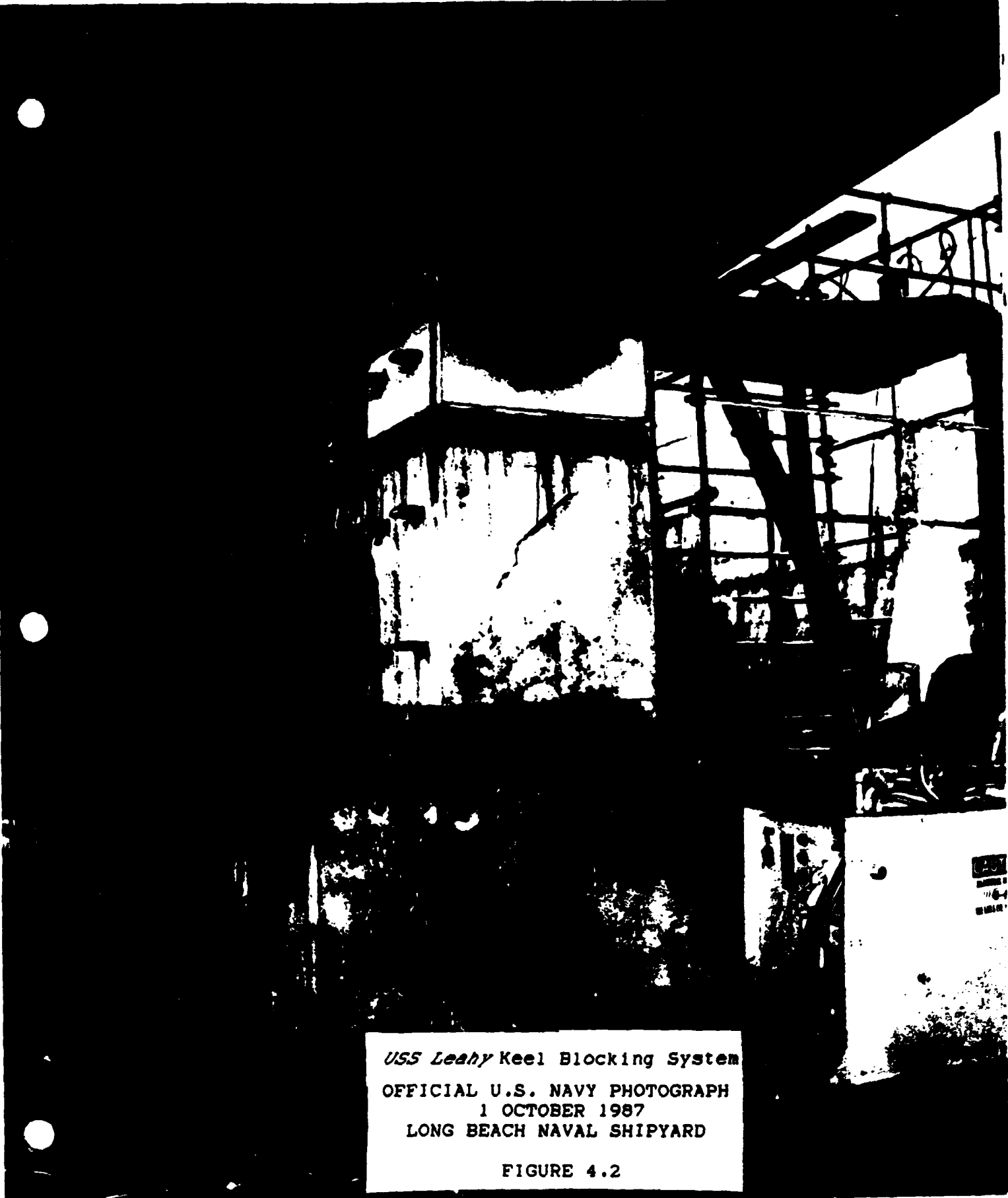
OFFICIAL U.S. NAVY PHOTOGRAPH  
1 OCTOBER 1987  
LONG BEACH NAVAL SHIPYARD

FIGURE 4.1

Figure (4.2) shows the keel block system of the *USS Leahy* looking forward. Again, there was no evidence of sliding or crushing along the keel line. This figure also shows the high blocking heights used by surface ships. Submarine blocking systems are usually much shorter. For a submarine, the bottom layer of blocks would not be present.

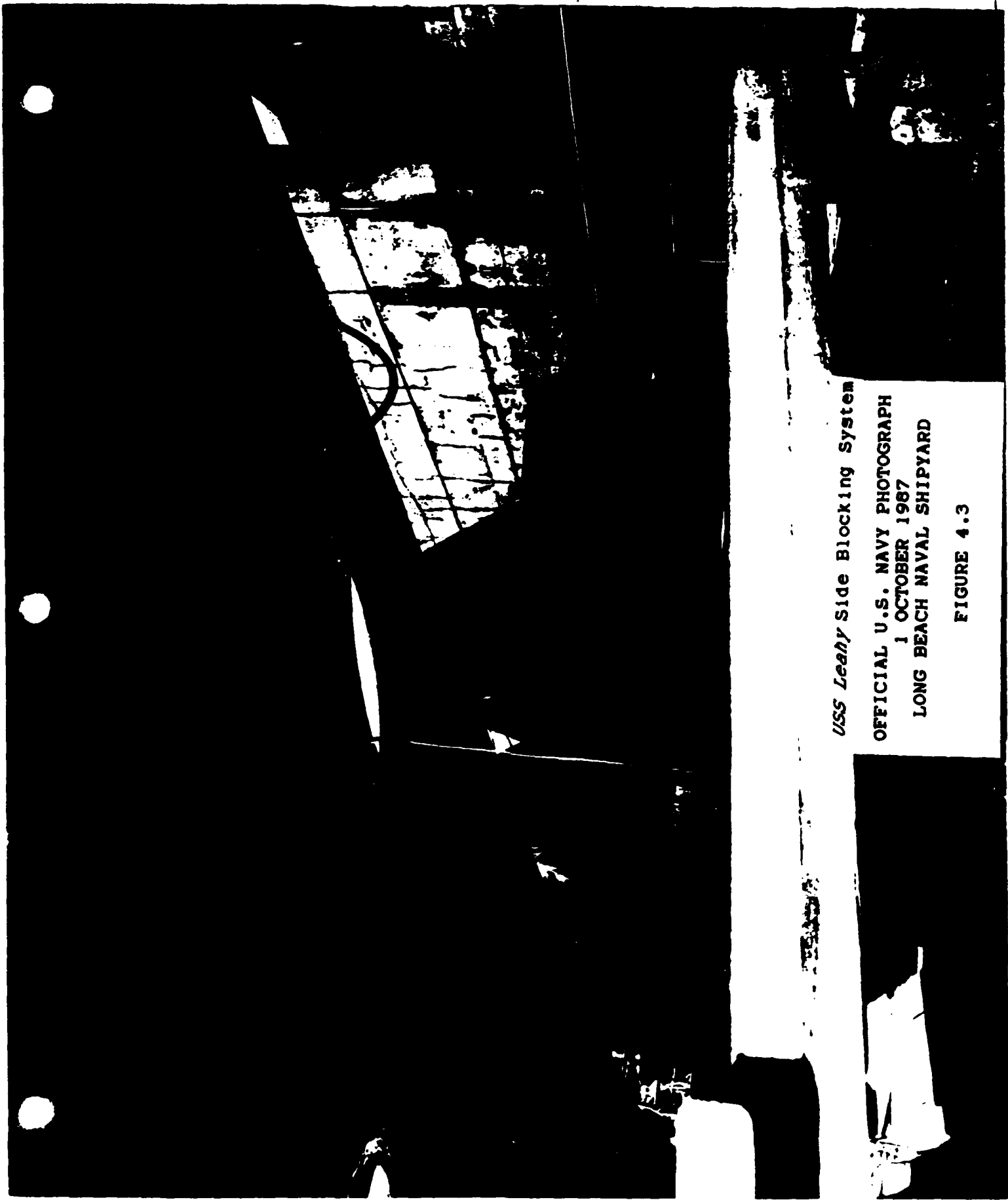
Figure (4.3) is a photograph of the *Leahy's* starboard forward side blocks. These two blocks were pushed away from the *Leahy* entirely and stayed away after the earthquake was over. This was also true for the same two blocks on the port side. The docking crew at LBNSY pushed these blocks back into position as much as possible, however, gaps can still be seen between the hull and the top of the side block cap. There were no such gaps before the earthquake. This photograph is also an excellent illustration of side block build up angle alpha ( $\alpha$ ) and side block cap angle beta ( $\beta$ ). In figure (4.4), a close-up of one of the aftermost starboard side block caps is shown. This photograph is another illustration of the side block sliding which occurred.

The dry docks at LBNSY are some of the only dry docks in the world instrumented with accelerographic equipment. These instruments were installed by the Naval Facilities Engineering Command and monitored by the Naval Civil Engineering Laboratory, Port Hueneme, California.



*USS Leahy* Keel Blocking System  
OFFICIAL U.S. NAVY PHOTOGRAPH  
1 OCTOBER 1987  
LONG BEACH NAVAL SHIPYARD

FIGURE 4.2



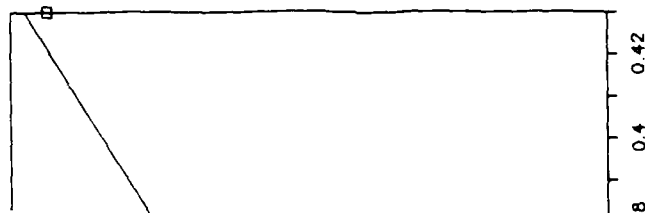
*USS Leahy* Side Blocking System

OFFICIAL U.S. NAVY PHOTOGRAPH  
1 OCTOBER 1987  
LONG BEACH NAVAL SHIPYARD

FIGURE 4.3

7 QUAKE

AP AIRTEL



USS Leahy Close Up of Side Block  
Showing Displacement  
OFFICIAL U.S. NAVY PHOTOGRAPH  
1 OCTOBER 1987  
LONG BEACH NAVAL SHIPYARD

FIGURE 4.4



When the 1 October 1987 earthquake occurred, all of the acceleration recorders (accelerographs) were triggered in the dry docks at LBNSY. The acceleration time histories were recorded on film in these instruments.

The closest accelerograph to the *USS Leahy* during this earthquake was located in dry dock #2 which is approximately 500 feet to the east of where the ship was drydocked. Dry dock # 2 is virtually identical in size and construction to dry dock # 3 where the *Leahy* was located. Figure (4.5) is a layout of LBNSY [10] waterfront and the location of the accelerograph and the *Leahy* are indicated. Figure (4.6) is a cross-section of dry dock # 3.

The accelerograph in dry dock # 2 was a SMA-1 Strong Motion Accelerograph. This instrument is a battery operated earthquake recorder designed to measure ground acceleration and structural response from strong local earthquakes. It provides tri-axially (orthogonally arranged longitudinal, vertical, and transverse) measured photographic records of the local acceleration time history [11]. Figure (4.7) is a photograph of this instrument.

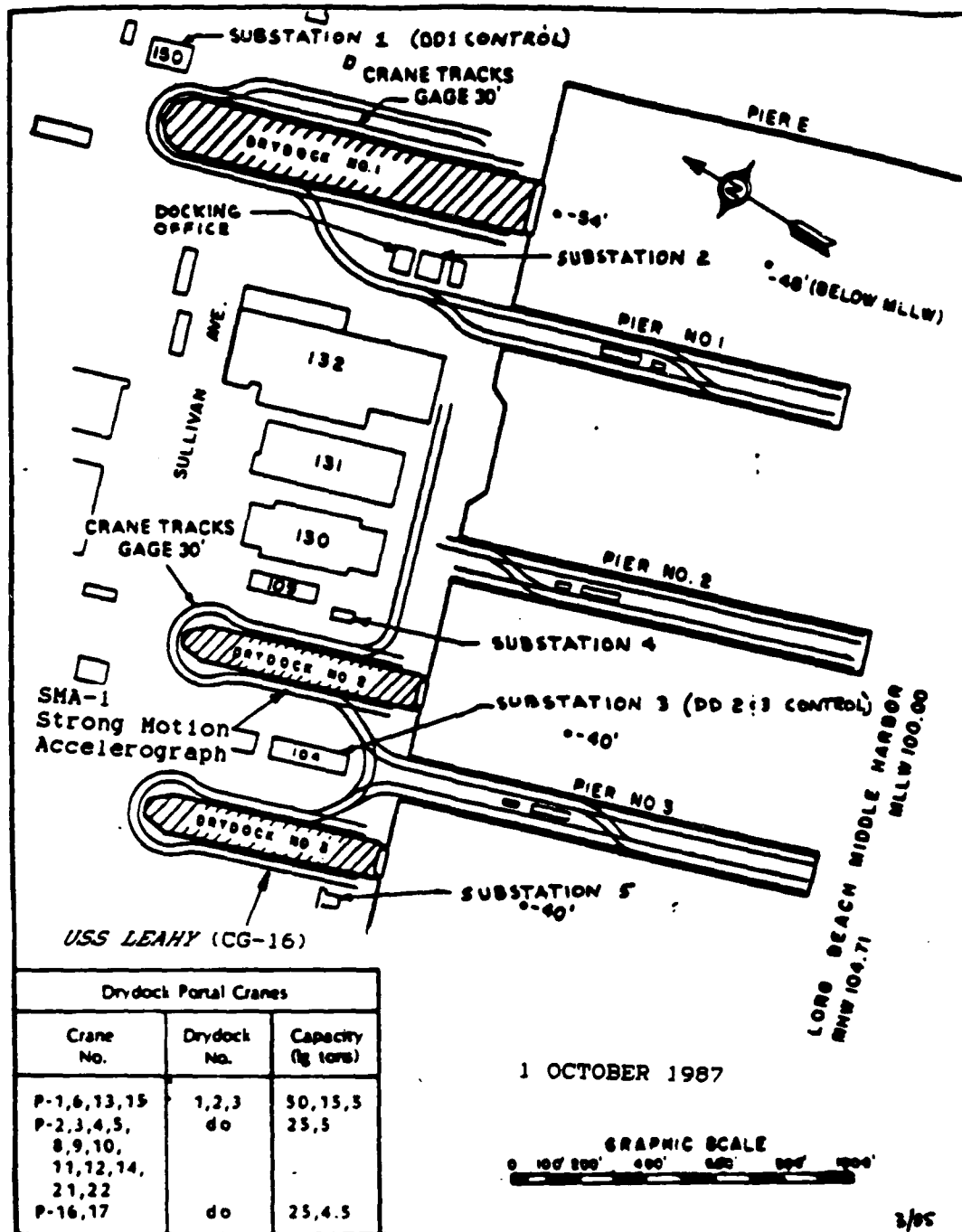
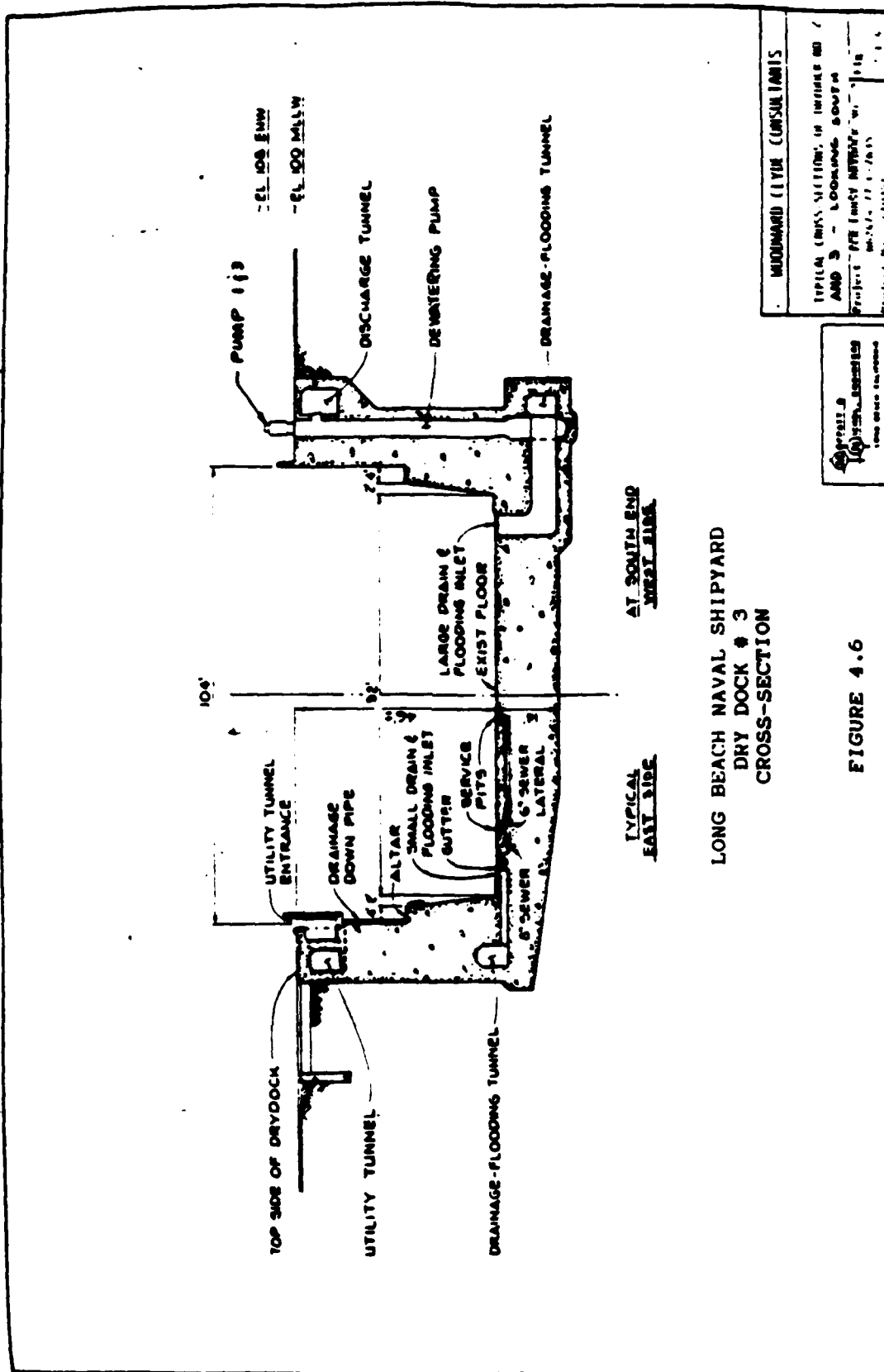
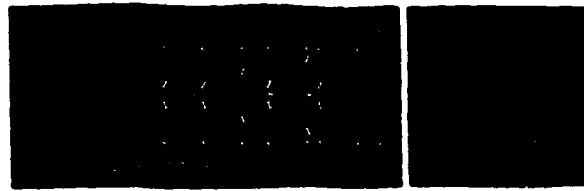


FIGURE 4.5  
Location of Drydocks, Long Beach Naval Shipyard, Long Beach, California  
NAVFAC DM-29.3 (NOV 81)





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## SMA-1

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Strong Motion Accelerograph

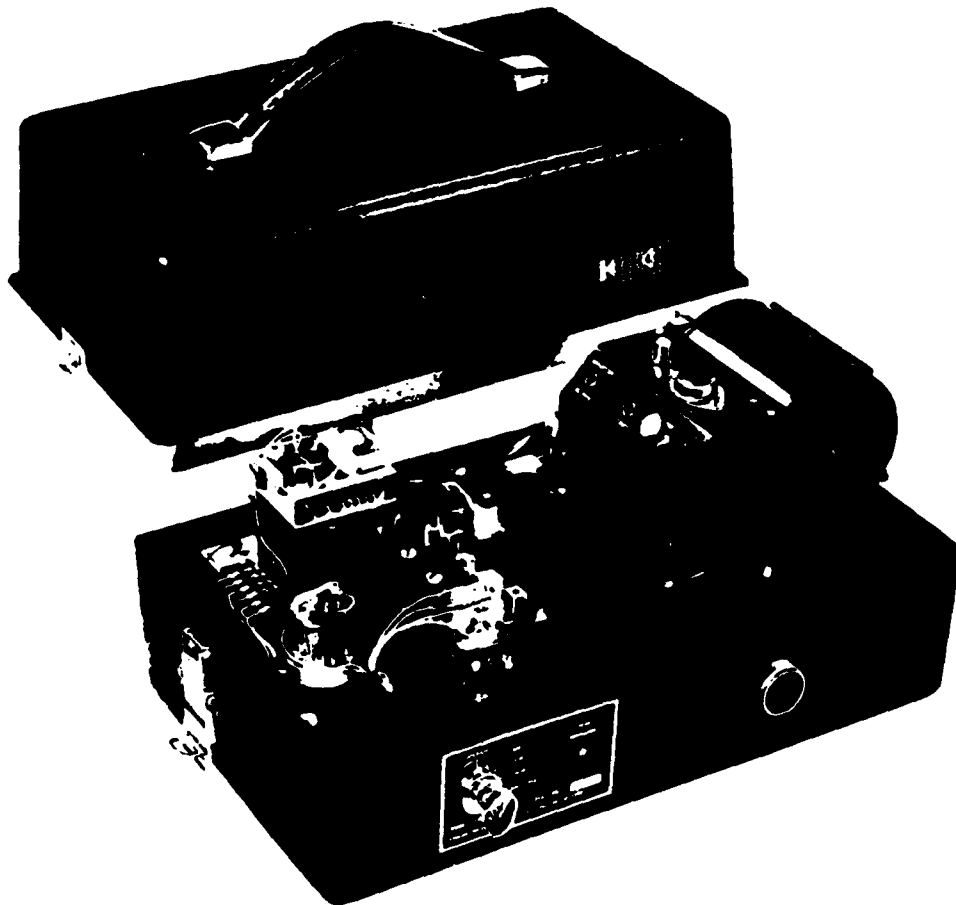


FIGURE 4.7

After the earthquake, the record from the SMA-1 in dry dock # 2 was taken to the Naval Civil Engineering Laboratory where the rough data was analyzed. This data was then corrected and processed by Structural and Earthquake Engineering Consultants, Arcadia, California. The corrections were necessary due to instrument bias and recording errors. The Naval Civil Engineering Laboratory forwarded these results, and they were used in this thesis to analyze the *Leahy's* blocking system response. The results [5] of data processing are called "corrected accelerograms" and are provided in the standard format magnetic media data file as used by the National Geophysical Data Center, Boulder, Colorado. The data provided was further processed for use in "3DOFRUB" using the support programs described in section 2.3. Figure (4.8) shows the corrected data plots provided by the Naval Civil Engineering Laboratory for dry dock # 2's transverse acceleration component. A typical header for one of the data files is included in Appendix 3.

The data from the SMA-1 took months to process due to its analog nature. Digital accelerograph instruments now exist which can provide immediate processed information to users via computer modems in the standard format. But these instruments are not yet installed in dry docks.

WHITTIER EARTHQUAKE OCT 01, 1987 11442 GMT  
 J100200 87.101.0 002 LBNY COMP TRN

ACCELERATION IS BAND-PASS FILTERED BETWEEN .300-.400 AND 25.00-27.00 CYC/SEC.

PEAK VALUES : ACCELERATION = 50.74 CM/SEC/SEC VELOCITY = 7.14 CM/SEC DISPLACEMENT = 1.33 CM

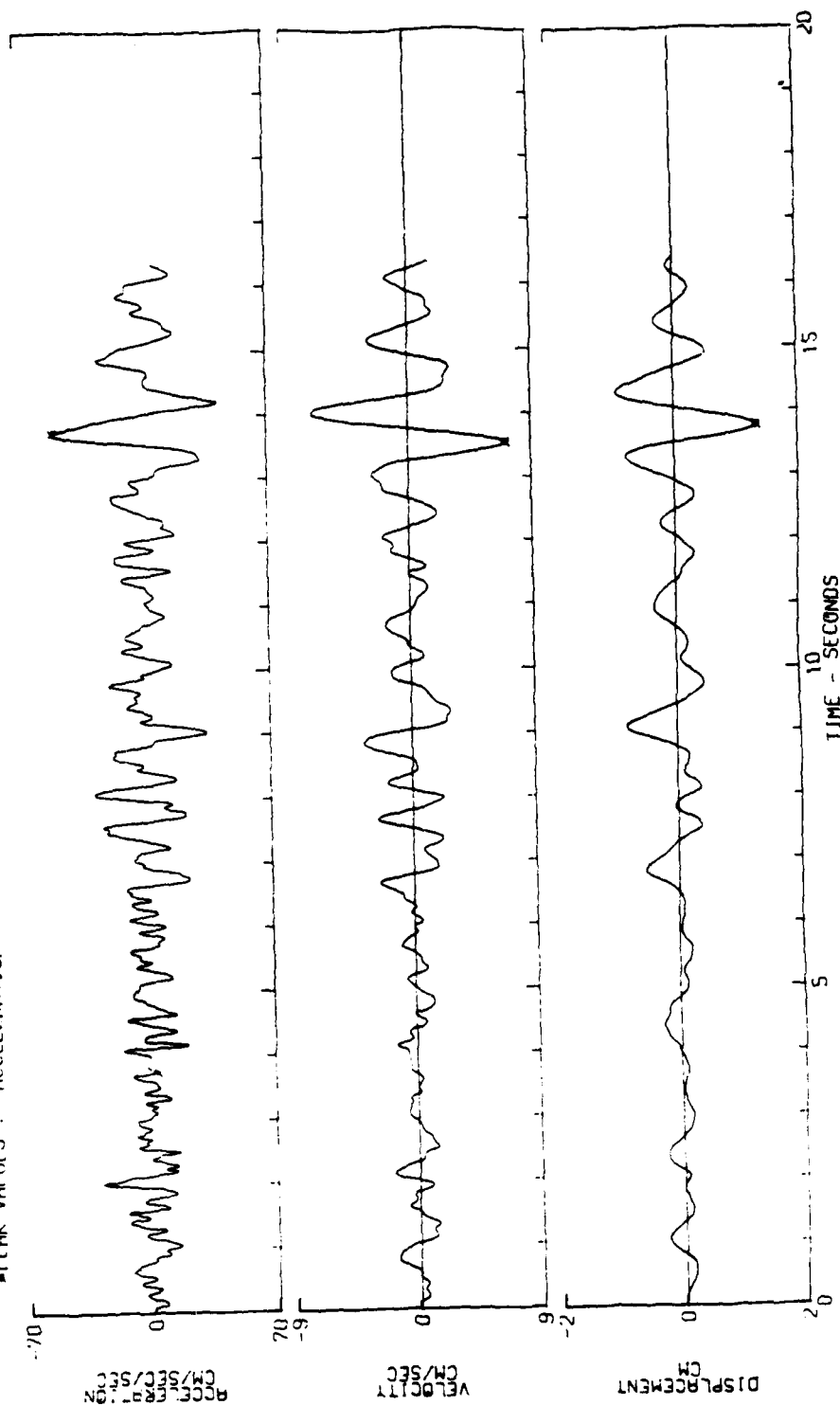


FIGURE 4.8

#### 4.1 Modeling of the *USS Leahy* Drydock Blocking System

The characteristics of the *USS Leahy's* drydock blocking system were obtained from the Docking Officer at LBNSY, Mr. Robert Dixson. The information used came from a "layout sheet" which was used to construct the blocking system. A copy of this "layout sheet" is included in Appendix 3. The following information is obtained from this sheet and is used in producing an input data file for the "3DOFRUB" computer program:

Side block height (htside)  
Keel block height (htkeel)  
Numbers of blocks  
Side block cap angles (beta)  
Side block breadths (br)

The photographs taken and visual inspection of the blocking system are used to determine material quantities and dimensions of each blocking layer. These dimensions are used in the blocking system stiffness spreadsheets. The features of the stiffness spreadsheets used are described in detail by Hepburn [1]. They are included in Appendix 3. The bilinear model is used to describe the Douglas fir caps. Also, in Appendix 3 is a summary of the *USS Leahy's* blocking system stiffnesses and the resulting QD values. This summary sheet

displays the other submarine system stiffnesses as a comparison.

The moment of inertia about the keel for the *Leahy* is calculated using a formula given by Gillmer & Johnson [12] based on the ship's beam for a destroyer type ship. A spreadsheet is used for this calculation and is included in Appendix 3. The ship is modeled as a "rigid body". This is considered reasonable for a cruiser type ship subject to a small earthquake. Since, each set of *Leahy's* side blocks has different heights, the *Leahy* system is modeled several times using each set's heights. A typical data file for the *Leahy* used by the "3DOFRUB" program is included in Appendix 3.

#### 4.2 Results of the *USS Leahy* Analysis

One of the most interesting things found in examination of the *Leahy's* blocking system is that the outboard displacement varied significantly from block to block. Figure (4.9) is a plot of measured outboard block displacement versus cap angle. This figure shows that as cap angle increases outboard side block displacement increases in a linear fashion. A best fit linear regression line is shown along with the data points.



# USS LEAHY CG-16 DURING 1 OCT 87 QUAKE

MEASURED BLOCK DISPLACEMENT OUTBOARD

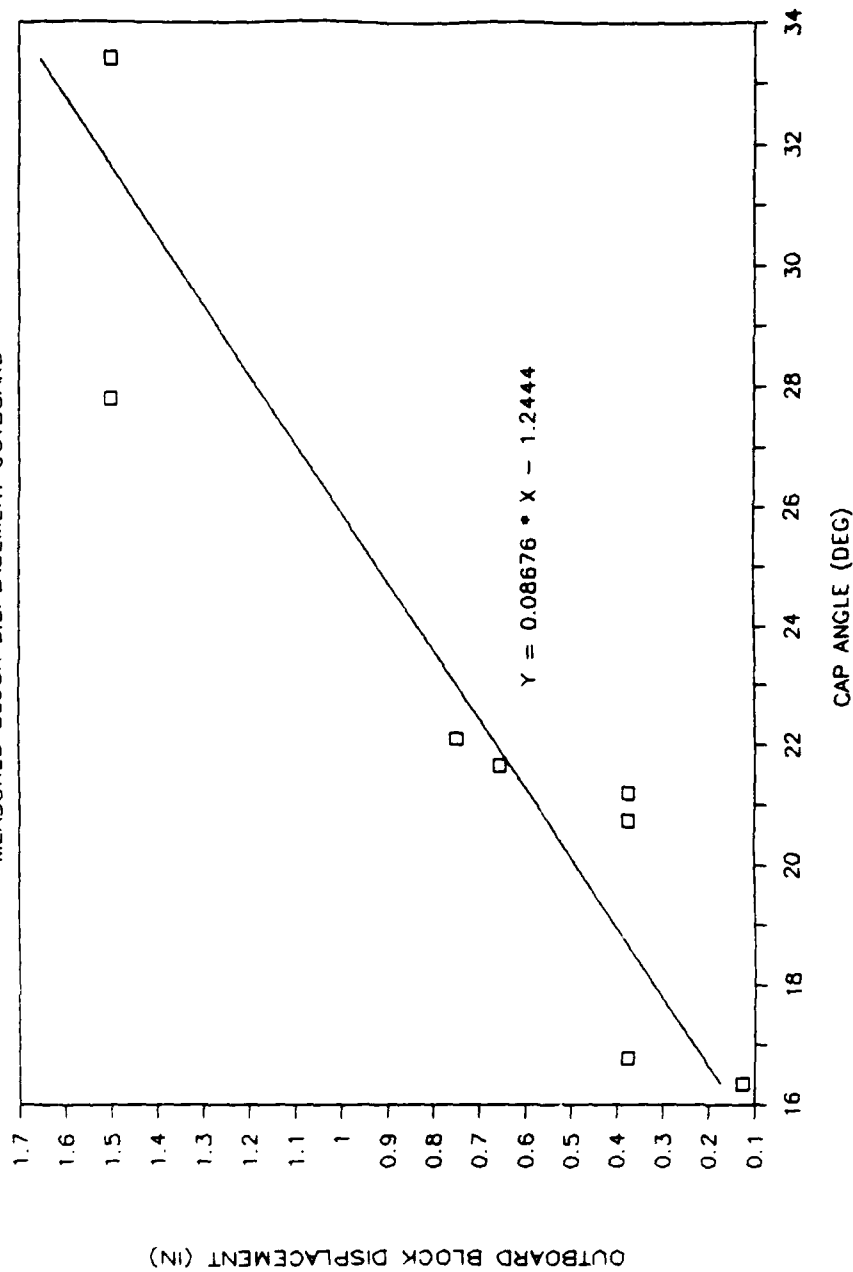


FIGURE 4.9

This type of behavior is consistent with the side block sliding analysis described in section 3.1 and incorporated in the "3DOFRUB" computer program. However, once sliding occurs, the three degree of freedom model used in "3DOFRUB" breaks down. There is no means incorporated into the program to determine the amount of side block displacement.

The next analysis step is to run "3DOFRUB" using each side block cap angle in the *Leahy's* blocking system. The program is run twelve times each time using a different cap angle. A relationship is found as seen in figure (4.10) between cap angle and the systems survivability when subject the dry dock # 2 acceleration time history. All of the analysis uses the transverse and vertical components of the dry dock # 2 acceleration time history.

It is observed that the block on block surfaces for this system had been painted. According to Rabinowicz (1987) [13], a reasonable estimate for the friction coefficient for this situation is 0.3. This value is used in comparing all of the cap angles. Figure (4.10) shows a linear relationship between earthquake survivability and cap angle. As cap angle increase the system's survivability decreases due to side block sliding.

# USS LEAHY CG-16 DURING 1 OCT 87 QUAKE

FRACTION ACCEL AT FAILURE VS. CAP ANGLE 1300 8/8 FRUIT,

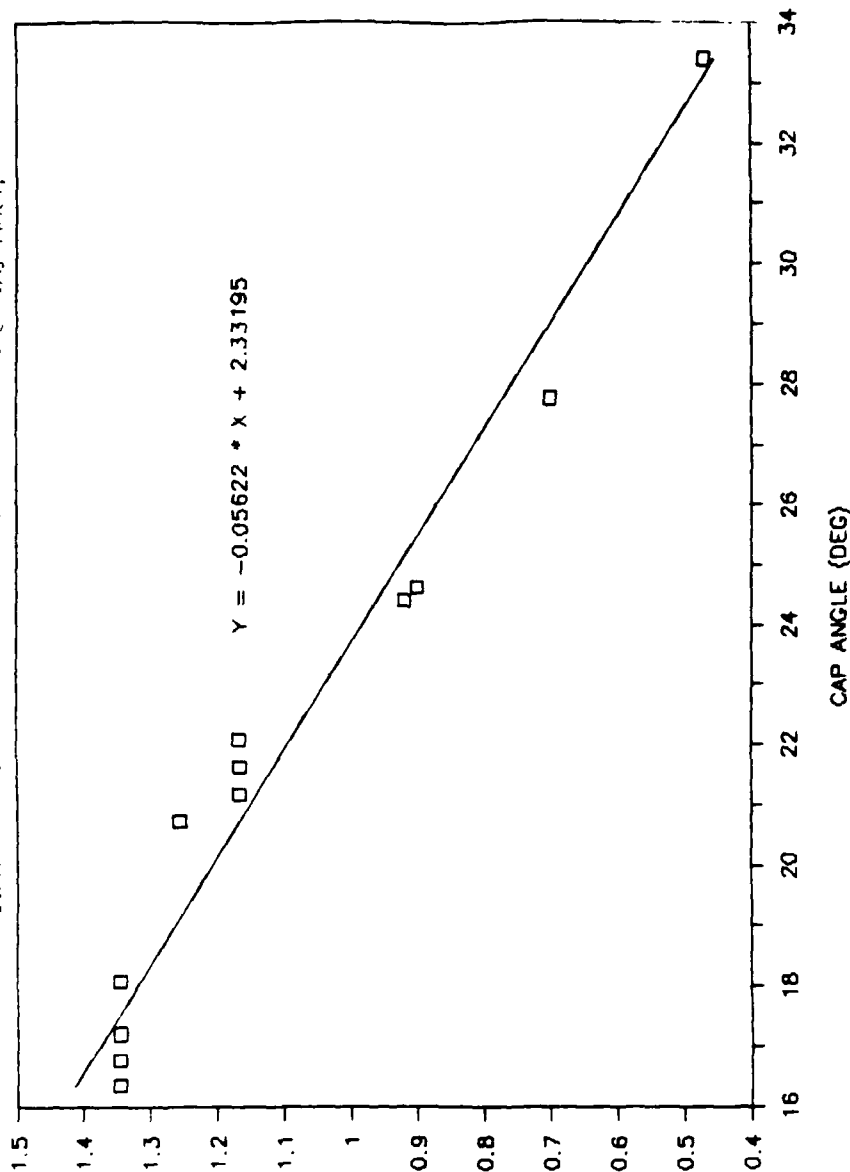


FIGURE 4.10

Figure (4.10) predicts that the following side blocks would slide when subject to the dry dock # 2 acceleration time history: (15, 14, 13, 7, 12, 6, 1, 4). All of these blocks were observed to slide. Side blocks are numbered from the stern forward. Blocks 14 and 15 are the farthest blocks forward on the port and starboard side.

The program predicts failure ranging from 47 to 117 % of the dry dock # 2 acceleration time history. The side block systems which are predicted to fail at the lowest acceleration time histories were those side blocks with the highest cap angles. This correlates very well with observed side block sliding failures on the *USS Leahy*. A spreadsheet including a regression analysis of the observed side block displacements for the *USS Leahy's* blocking system is included in Appendix 3.

The model predicts side block sliding failure as the primary failure mode for the *USS Leahy* system subject to the dry dock # 2 acceleration time history. This is precisely the actual system failure observed. The model also predicts that side block liftoff is the primary failure for side blocks with small cap angles. Again, this is consistent with observations of the side blocks. The observed variations in the data as seen in figure (4.9) could be due to such factors as frictional and material variations among the side block piers.

An analysis is then conducted to determine the effects of varying the frictional coefficient on system survivability. For this study, cap angle is held constant as are all other parameters except the block on block frictional coefficient. Side block # 13 is used in this study. This block has a cap angle of 0.43 radians which is in the middle of the side block cap angle range. The block on block friction coefficient is varied above and below the 0.3 value as shown in figure (4.11).

Figure (4.11) shows that there is a very strong linear dependence of survivability on block on block frictional coefficient. Varying the friction coefficient from 0.22 to 0.43 results in a survivability range of 22 to 175 % of the dry dock # 2 acceleration time history. The best fit line as well as the data points are shown on the figure. One key result is that it seems that a block on block friction coefficient of 0.3 best fits the observed sliding conditions which occurred on the *USS Leahy*. A 0.3 value corresponds to failure at 80 % of the earthquake which is reasonably close to where the sliding of the side blocks similar to # 13 appeared to occur.

# USS LEAHY CG-16 DURING 1 OCT 87 QUAKE

FRACTION ACCL AT FAILURE VS. B/B FRICT. COEF. "130 CAP AT 1/4"

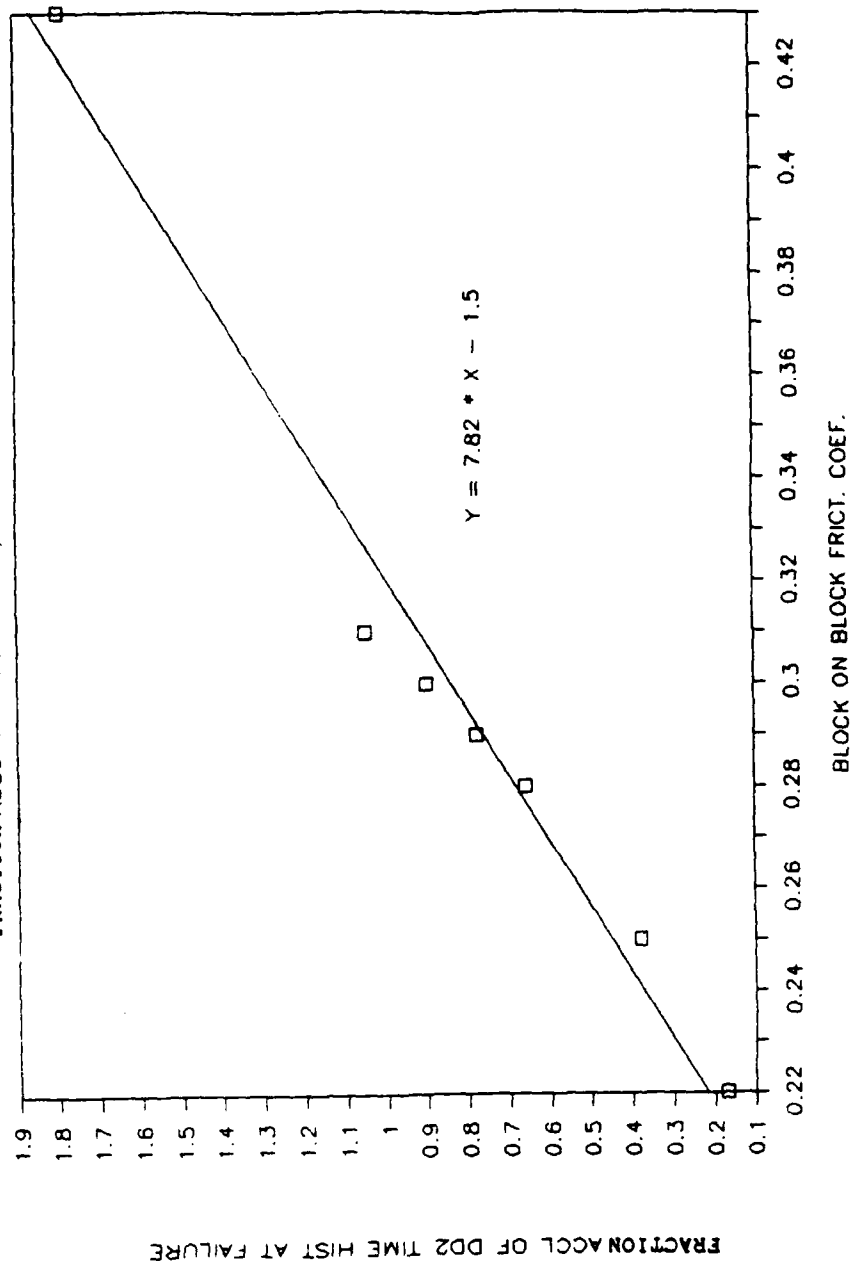


FIGURE 4.11

Figure (4.12) is the output from "3DOFRUB" for the vertical displacement of the *Leahy's* starboard side blocks (assuming # 13 cap angle and height) during the earthquake. It shows that slight liftoff does occur about 8 seconds into the earthquake where the displacements become negative. This also correlates well with the observed slight liftoff which occurred. A typical "3DOFRUB" output run is included in Appendix 3. Based on these results, the three degree of freedom model and the "3DOFRUB" computer program appear to correctly reflect the behavior of an actual drydock blocking system including the effects of side block geometry.

# USS LEAHY YPRIME VERSUS TIME

100% 1 OCT 87 WHITTIER/DD2 TIME HISTORY

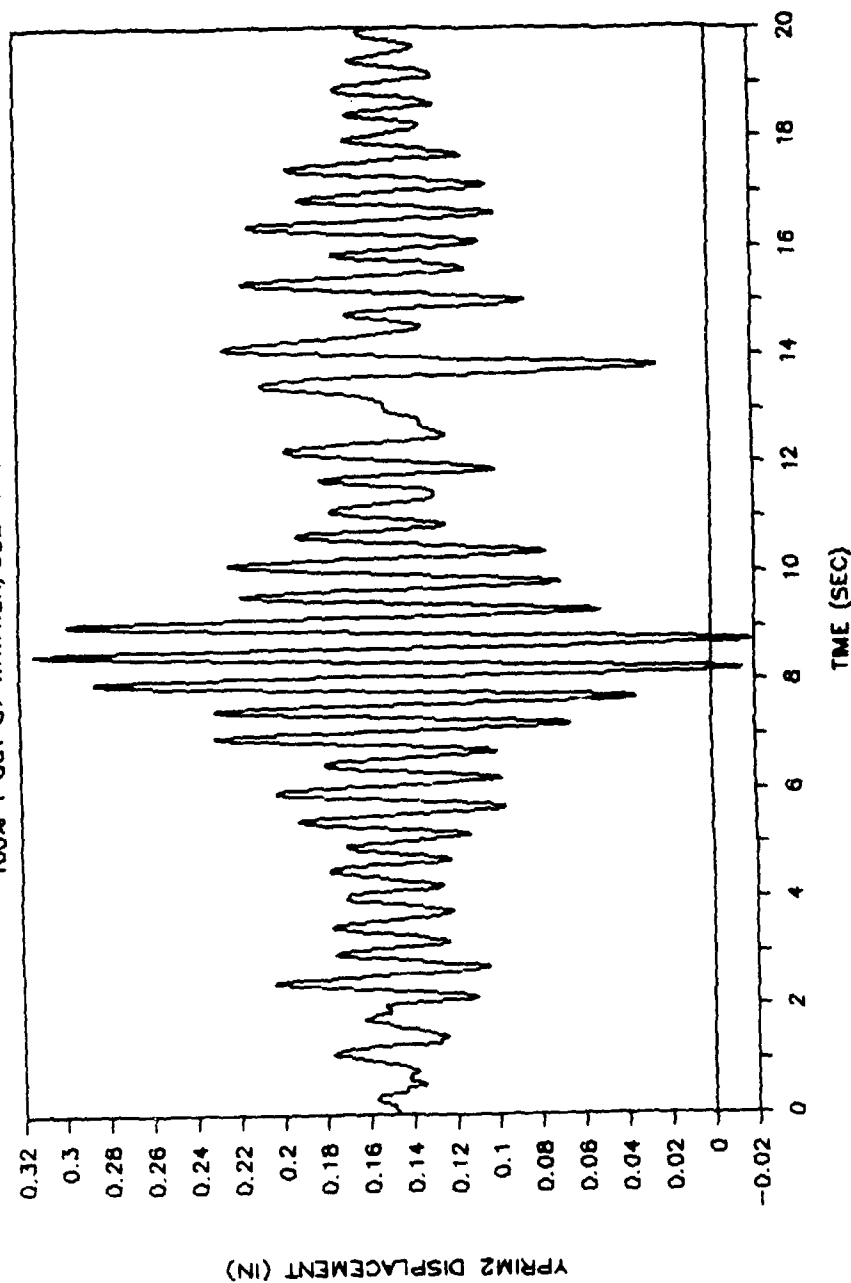


Figure 4.12 USS Leahy CG-16  
Right Side Block Vertical Displacement vs. Time  
100 % 1 October 87 Whittier Time History



## CHAPTER 5

### WALE SHORE, ISOLATOR, AND BLOCK STIFFNESS/GEOMETRY VARIATION PARAMETRIC STUDIES

#### 5.0 Parametric Study Description

It has already been seen that present U.S. Navy drydock blocking systems are inadequate to resist expected earthquake accelerations. Some potential new materials such as rubber caps and dynamic isolators look promising in correcting this problem. Many other design improvements including the use of wale shores, stiffening the side blocks, and widening the blocking system base show potential. In order to explore these possibilities and establish a feel for the design space, a series of parametric studies using the "3DOFRUB" computer program are conducted.

Due to the high number of runs expected to accomplish this study, the Naval Sea Systems Command main frame (VAX) computer was used. This reduced the run time of "3DOFRUB" from several minutes to seconds. The system portability built into the "3DOFRUB" source code allows it to be recompiled for use on the VAX computer with very few minor changes. These parametric studies took several days and involved several hundred runs.

In order to determine the design space, wale shore stiffness and side block and keel block horizontal and

vertical stiffnesses inputs to "3DOFRUB" are varied. These values are not related to any particular existing or potential blocking system. These values are input directly into the program without first being produced by the stiffness spreadsheets. Submarine drydock blocking system # 1 is used as a baseline for these studies. In all cases except for the study of systems with wale shores and 1 inch rubber block caps (system 50 series), a linear material analysis is used. The 1940 El Centro earthquake acceleration time history used by Hepburn [1] is used throughout this parametric study. For several of these studies, the effect of doubling the keel block widths is investigated.

### 5.1 Parametric Study Results

The results of system # 1 vertical side block stiffness variations on failure due to the 1940 El Centro earthquake is shown in figure (5.1).  $\log(kvs)$  with respect to 1 kip/in is plotted against failure fraction of the earthquake. For each stiffness, failure fractions due to all failure modes present are plotted. The primary failure modes for this system are side block liftoff, keel block overturning, side block overturning, and side block sliding. For this particular study, side block horizontal stiffness is held constant at 100,000 kips/in.

# SIDE BLOCK VERTICAL STIFFNESS VERSUS FAILURE

Ksh = 100000 kips/in ALL MODES

FAILURE FRACTION OF 1940 EL CENTRO EARTHQUAKE

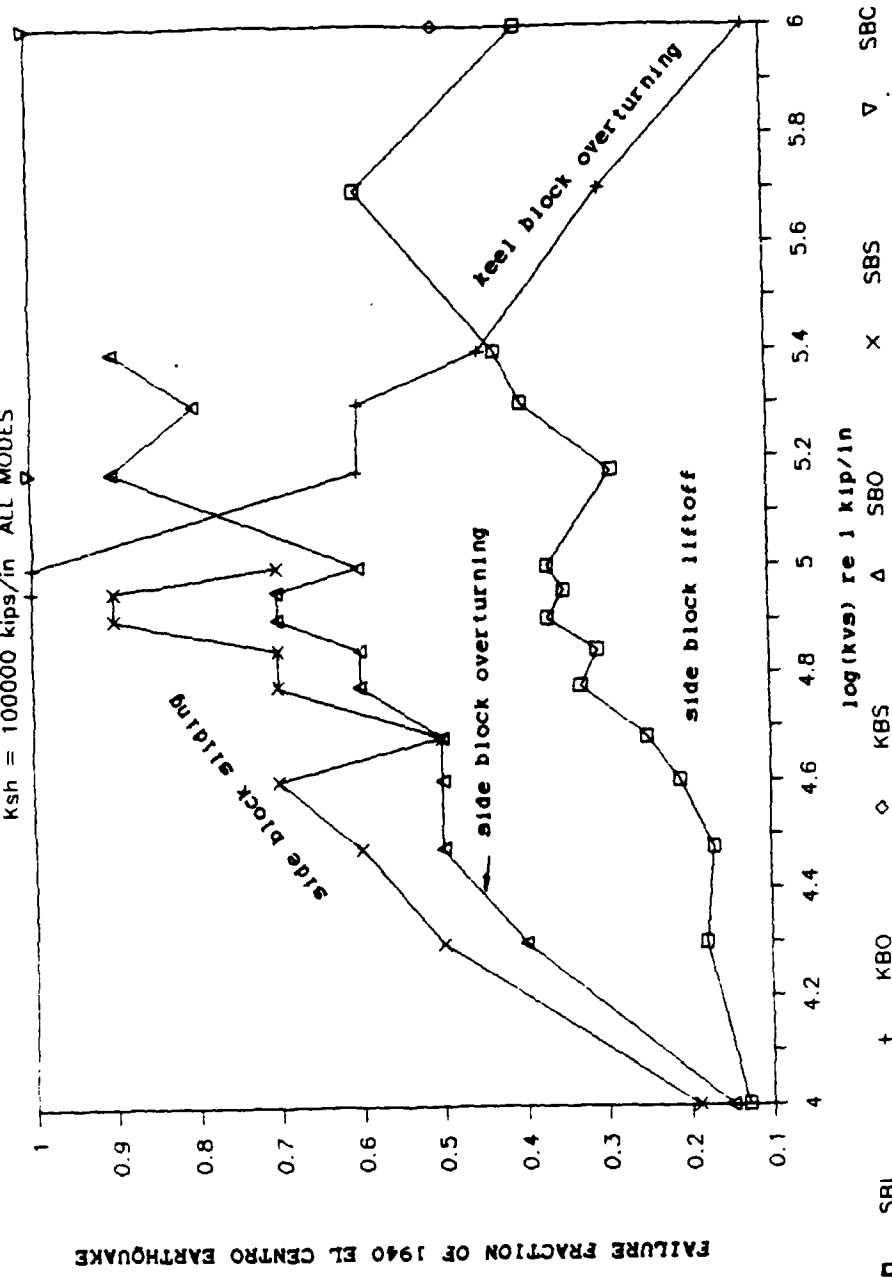


FIGURE 5.1

Since all failure modes are shown in figure (5.1), their relative dominance can be seen. The curve showing overall system failure for each stiffness consists of the lines connecting the bottom failure modes in the figure. Therefore, the modes of failure which dominate this system are side block liftoff and keel block overturning. Side block liftoff is dominant from  $\log(kvs) = 4$  to 5.4, and keel block overturning is dominant from  $\log(kvs) = 5.4$  to 6.

The best survivability attained by varying side block vertical stiffness is 40 % of the El Centro earthquake. While there is some promise in increasing side block vertical stiffness, it is still not possible to meet the 0.2 g criteria by increasing this stiffness alone. Also, the horizontal and vertical stiffnesses required are extremely high and may not be practically obtainable in an actual submarine drydock blocking system.

Another key factor evident in figure (5.1) is that side and keel block overturning are important issues. As stiffness increases, side block overturning and sliding become less important; however, above 100,000 kips/in keel block overturning quickly becomes increasingly important until it dominates. It is clear that any design strategy must take into account both preventing side block liftoff and keel block overturning. As one failure mode is eliminated, another will

come to dominate; therefore, a design strategy that overcomes the various failure modes at the same time is required.

Figure (5.2) shows the results of varying side block horizontal stiffness. In this case,  $k_{vs}$  is held constant at 70,000 kips/in while  $k_{hs}$  is varied. As shown in the figure, keel block overturning is the dominant failure mode up to  $\log(k_{hs}) = 4.3$  after which slide block liftoff became dominant.

Since the failure fraction reaches a plateau at  $\log(k_{hs}) = 4.6$  up to 5, this appears to be an upper design limit for horizontal stiffness above which little increase in survivability occurs. From these and other parametric studies it is found that for optimal survivability, both horizontal and vertical side block stiffness have to be increased together. Again, this shows that a parallel design effort is required. Varying one parameter alone does not result in a successful design.

Results of using wale shores of various stiffnesses on system # 1 survivability are shown in figure (5.3). Rapid improvements in system survivability occur as wale shore stiffness is increased. To prevent the occurrence of keel block overturning, double width keel blocks are used in this study.

# SIDE BLOCK HORIZONTAL STIFFNESS VERSUS FAILURE

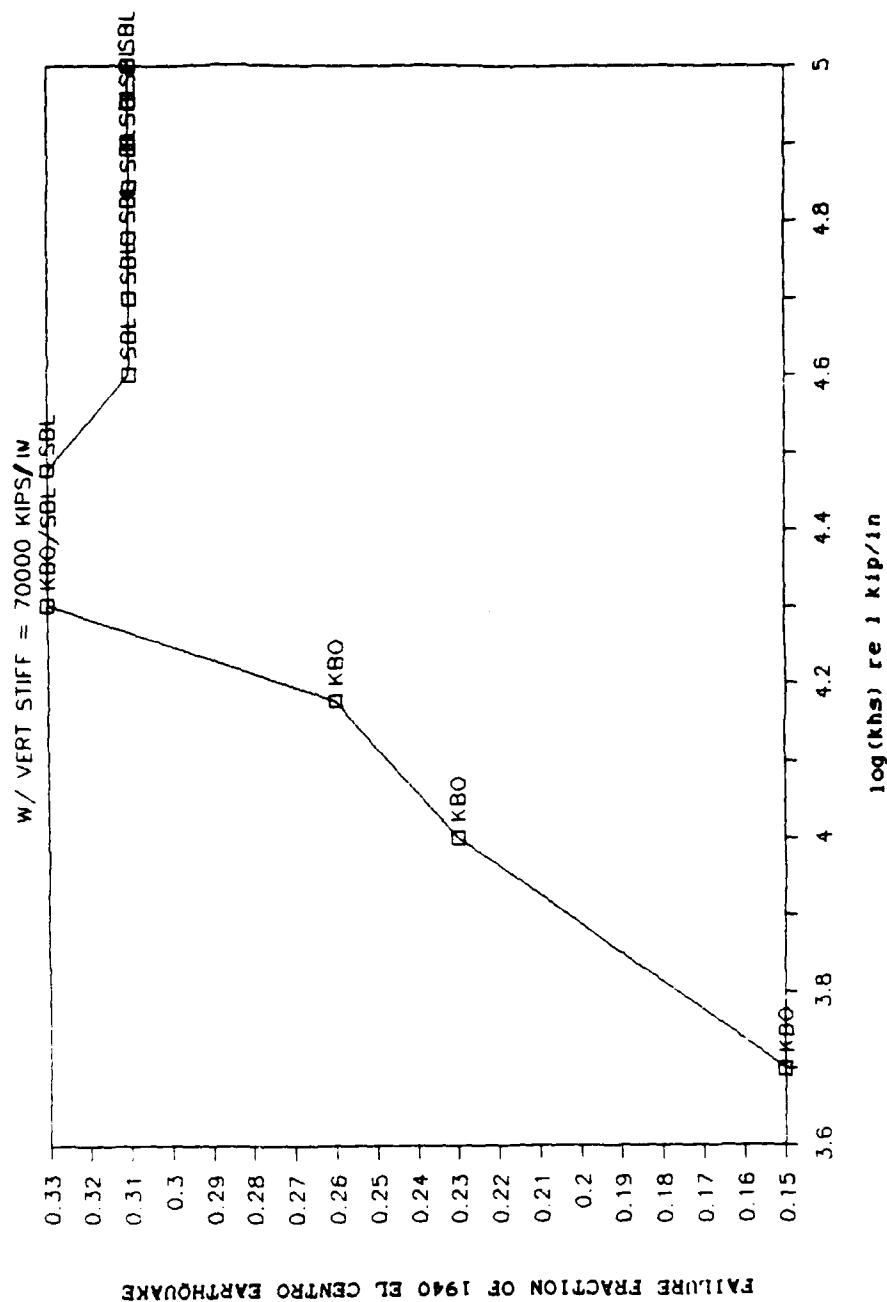


FIGURE 5.2

# WALE SHORE STIFFNESS VERSUS FAILURE

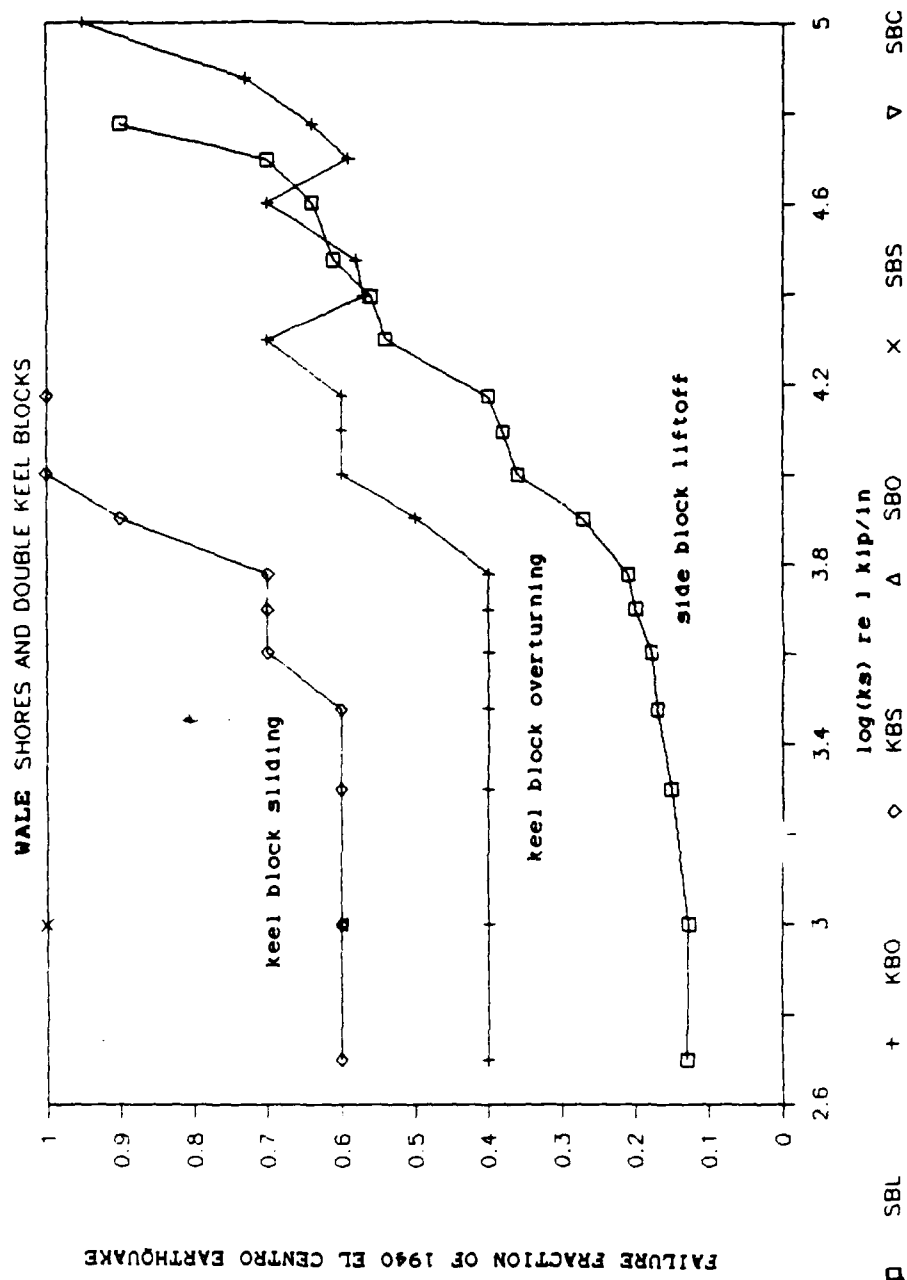


FIGURE 5.3

As seen in figure (5.3), the three primary failure modes are side block liftoff, keel block overturning, and keel block sliding. Side block liftoff is dominant up to  $\log(ks) = 4.4$ . Keel block overturning overtook side block liftoff and dominates failure for  $\log(ks) = 4.6$  and above. The best survivability seen is 60 % of the El Centro earthquake which is well above the 0.2 g criteria. Therefore, the use of wale shores is quite promising, and the required stiffness appears obtainable.

The use of wale shores increases system survivability by reducing the rotation and horizontal displacement of the submarine during the earthquake. This is due to the large restoring moment provided by the wale shores resulting from their high position above the keel baseline. Wale shores also shift the horizontal and rotational system modal frequencies well above the excitation frequencies of the earthquake.

When the side and keel blocks are prevented from overturning and 1 inch of rubber is added to the block caps, extremely high system survivability can be obtained using wale shores. Figure (5.4) shows the results of varying wale shore stiffness. It is found that the use of 1 inch rubber caps alone more than doubled system survivability. This is due to the rubber cap delaying side block liftoff. The wale stiffness is then varied up to the optimum stiffness values, 30,000 kips/in, shown in figure (5.3).



# SURVIVAL VS. WALE SHORE STIFFNESS

SYSTEM 50 SERIES 1940 ELCENTRO QUAKE

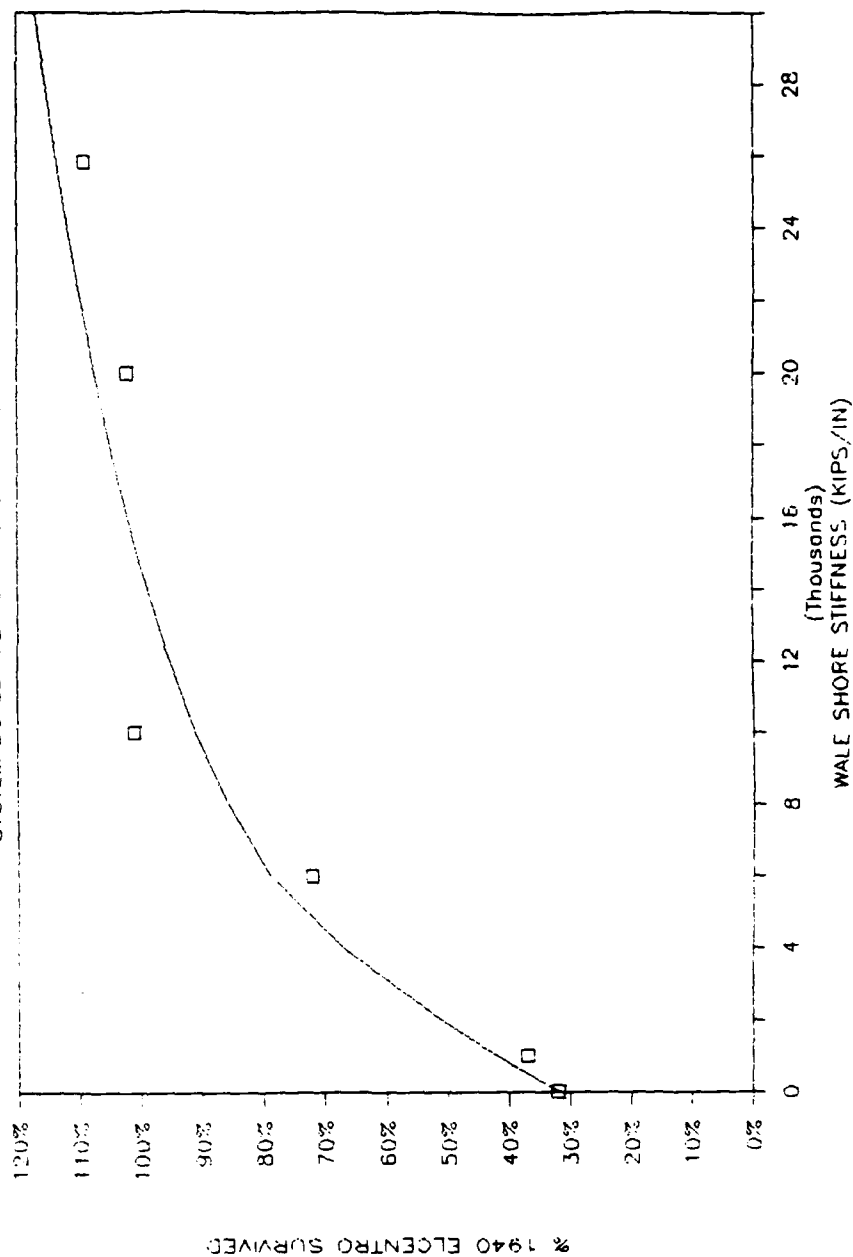


FIGURE 5.4

By increasing the wale shore stiffnesses, survivability increased quickly up to about 80 % of the El Centro earthquake. After this magnitude of earthquake, increasing wale shore stiffness gave diminishing returns. This study indicates that wale shores are a viable solution to the submarine drydock blocking survivability problem. Details of the wale shore design solution are given in chapter 8.

## CHAPTER 6

### DRYDOCK BLOCKING SYSTEM SURVIVAL COMPARISONS AND SITE SPECIFIC EFFECTS

#### 6.0 Drydock Blocking System Survival Comparisons

The eleven submarine drydock blocking systems analyzed by Hepburn [1], Sigman [2], and Karr [3] are again analyzed in this thesis to determine the effect of including the geometric modifications described in chapter 3. The "3DOFRUB" computer program is run using the 1940 El Centro earthquake acceleration time history and data files describing each of the eleven systems. For purposes of comparison, the eleven systems are modeled as linear-elastic. The bilinear system data files used by Hepburn [1] are modified by setting QD's equal to zero and setting the plastic stiffness values equal to the elastic values.

Figure (6.1) is a plot comparing the survivability of Sigman's [2] eleven submarine systems to the linear systems. The purpose of this comparison is to determine what effect the side block buildup angle ( $\alpha$ ), side block cap angle ( $\beta$ ), and side block wedge effect has on system survivability. The figure shows that the geometric effects has little impact on overall system survivability. In some cases survivability is improved, and in other cases it is decreased.

# SURVIVAL % COMPARISONS

SIGMAN VERSUS LINEAR

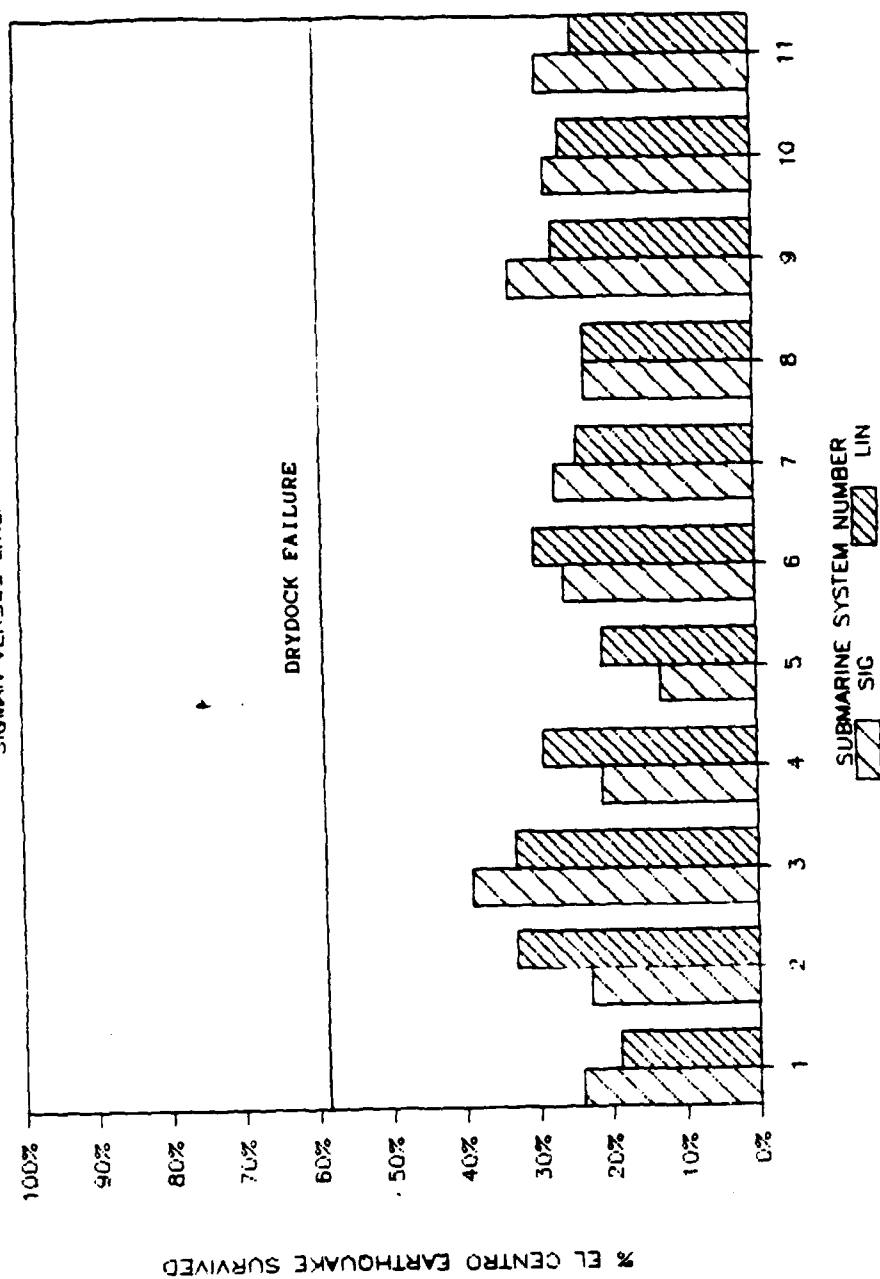


FIGURE 6.1

The average value for survivability for all eleven systems is 26 % for both the linear and Sigman analyses. This is not surprising since submarines have relatively low side block heights above baseline and low cap angles. Therefore, Sigman's assumption that submarines have zero side block height above baseline is reasonable. However, as seen by the *Leahy* case study in chapter 4, the geometric modifications made to "3DOFRUB" become important in the case of surface ships due to high side block heights and large cap angles.

Figure (6.2) is a plot comparing the survivability of Hepburn's [1] eleven bilinear submarine systems to the linear systems. In this comparison there is a clear difference in survivability between the two studies. Overall, linear systems survive a higher earthquake percentage (26 %) than bilinear systems (23 %). There is no case where the bilinear systems survive a larger earthquake than the linear systems. Systems 5, 6, 7, and 8 survive the same earthquake magnitude. For these systems, large cap areas are present and the Douglas fir caps do not undergo plastic deformation. In every other case, the cap does plastically deform causing the Douglas fir to incur permanent set thus causing earlier side block liftoff.

# SURVIVAL % COMPARISONS BILINEAR VERSUS LINEAR

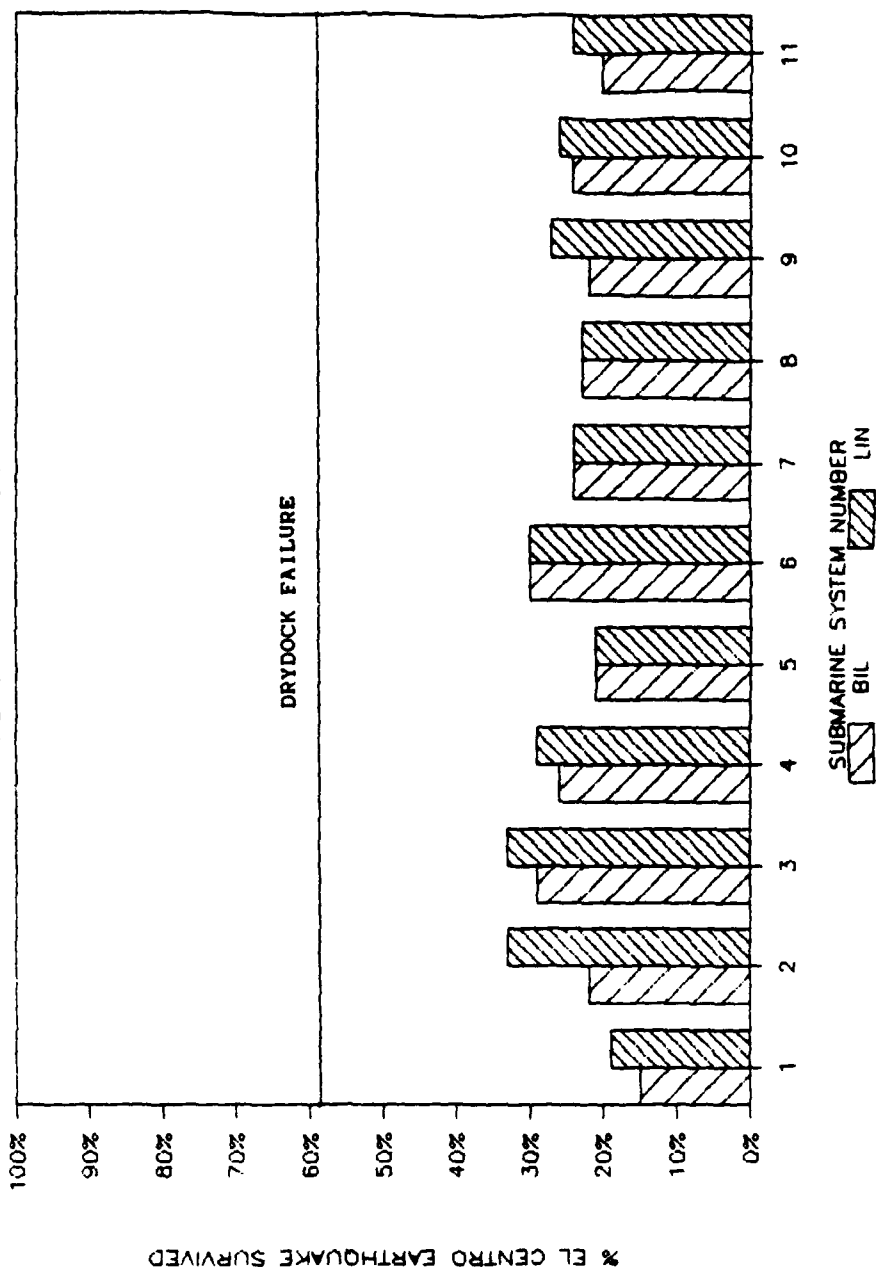


FIGURE 6.2

This comparison shows that Hepburn's [1] bilinear analysis was more conservative by approximately 10 percent. The bilinear analysis is a more cumbersome method. The linear method can be used to approach an adequate design, then the bilinear method can be used to fine tune the design to assure survivability.

#### 6.1 Earthquake Site Specificity

Earthquakes differ widely in magnitude, frequency, and duration. Their effect on local structures is also dependent on the immediate geological characteristics of the surrounding area. For this reason, using the 1940 El Centro earthquake acceleration time history alone is not considered adequate to develop a satisfactory submarine drydock blocking system design.

In the case of the 1 October 1987 Whittier earthquake, measured ground acceleration varied tremendously depending on the distance and direction from the epicenter. In addition, some areas further away from the epicenter felt larger accelerations than closer locations. Appendix 4 contains a report from the California Division of Mines and Geology [9] regarding the data from the Whittier earthquake .

The frequency spectrum of the recorded ground accelerations also depend on local geological conditions [9] [14]. Dry dock # 2 at Long Beach Naval Shipyard, where accelerations were measured, is located approximately 20 miles from the epicenter of the Whittier earthquake [15]. Figure (6.3) is a map produced by the California Division of Mines and Geology [9] which shows the locations of the epicenter and Long Beach Naval Shipyard. The ground acceleration was reduced from 0.45 g's peak acceleration near the epicenter to 0.052 g's peak in dry dock # 2.

In addition the dominant frequency of the earthquake was reduced from approximately 2 HZ near the epicenter to near 1 HZ in dry dock # 2. Mr. Lew from the Naval Civil Engineering Laboratory [14] stated that this reduction in frequency was not unique to the dry dock. This frequency was experienced throughout the Los Angeles harbor area.

Mr. Lew [14] stated that dry dock # 2 is sitting on an aquifer which exhibits dynamic characteristics similar to a solid. Along the sides of the dry dock is a layer of solid material rising approximately 10 feet above the aquifer. A 30 foot deep hydraulic layer exists above this solid material. Above this is a compacted land fill layer. This combination of geological properties around the dry dock contributes to the relatively low ground acceleration frequencies experienced.



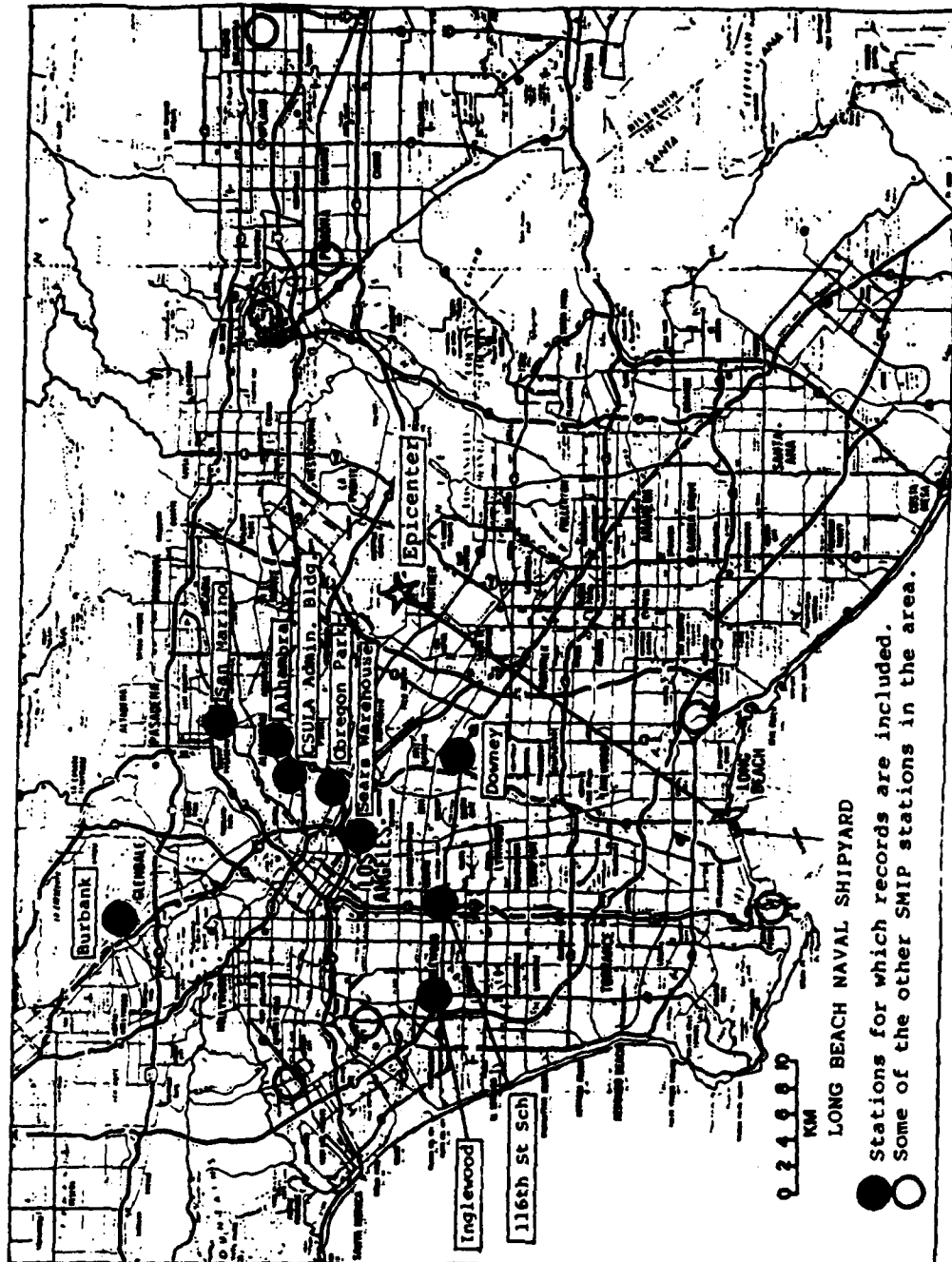


FIGURE 6.3  
1 October 87 Whittier Earthquake  
Epicenter and Long Beach Naval Shipyard Locations

For dry dock # 2 acceleration time histories, both the vertical and horizontal components were available. Figures (6.4) and (6.5) are the acceleration time histories in the horizontal and vertical directions respectively. These two plots show that the two components do substantially differ in magnitude and frequency content.

The Nuclear Regulatory Commission requires that earthquake acceleration time histories used in structural analysis incorporate the actual vertical and horizontal acceleration components when available. Otherwise, statistically independent vertical and horizontal acceleration time histories must be used with the vertical being two-thirds the magnitude of the horizontal component [16].

The geological conditions which exist at Long Beach Naval Shipyard are very similar to conditions at other graving dock locations. Lew [14] also stated that Mare Island Naval Shipyard's can withstand a maximum of 0.26 g's before the construction joints of the dry dock give-way. This value is used as the "dry dock failure" level in this thesis. Mr. Lew stated that the dry docks at Long Beach probably have the same design limitation. The dry docks at both these locations are very similar in construction.

# 1 OCT 87 WHITTIER CA EARTHQUAKE

LBNSY DD2 HORIZONTAL COMPONENT

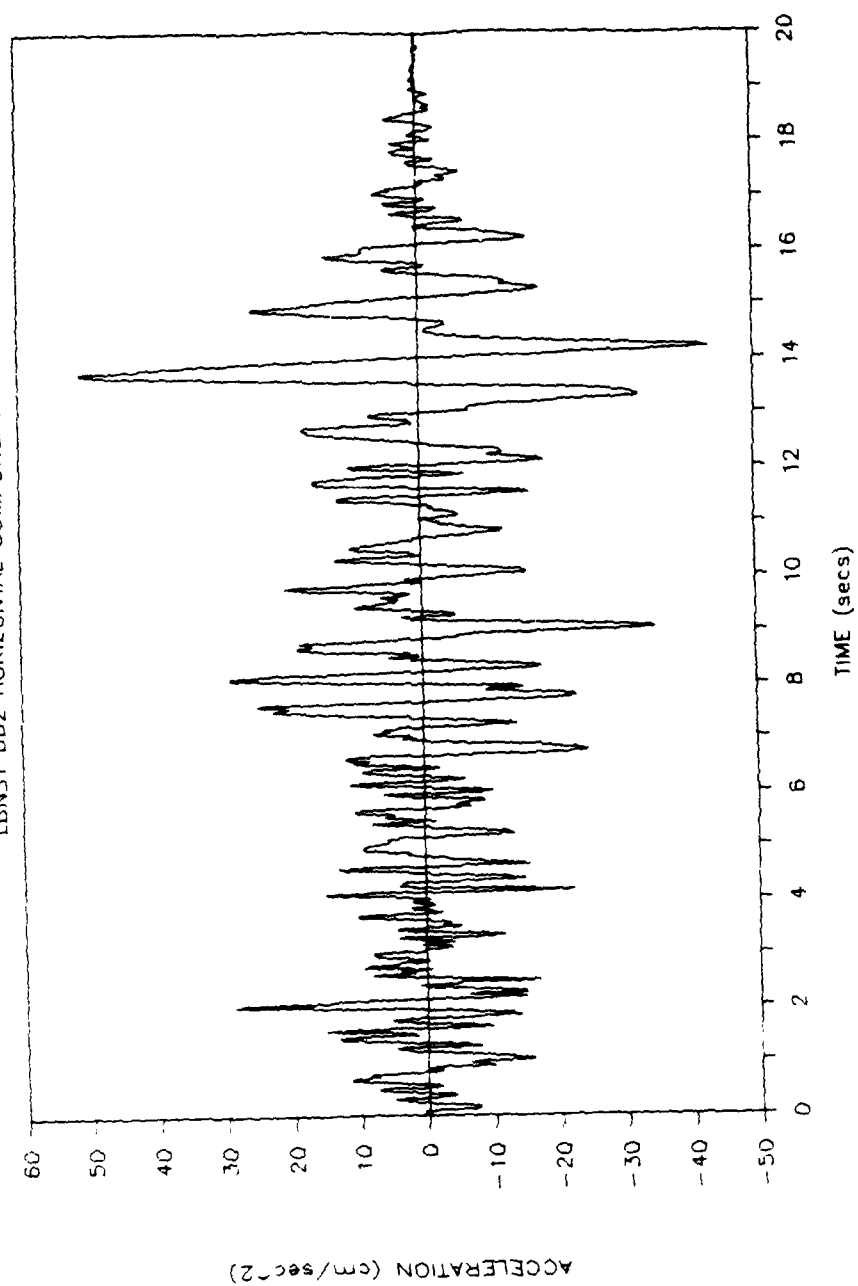


FIGURE 6.4

# 1 OCT 87 WHITTIER CA EARTHQUAKE

LBNSY DD2 VERTICAL COMPONENT

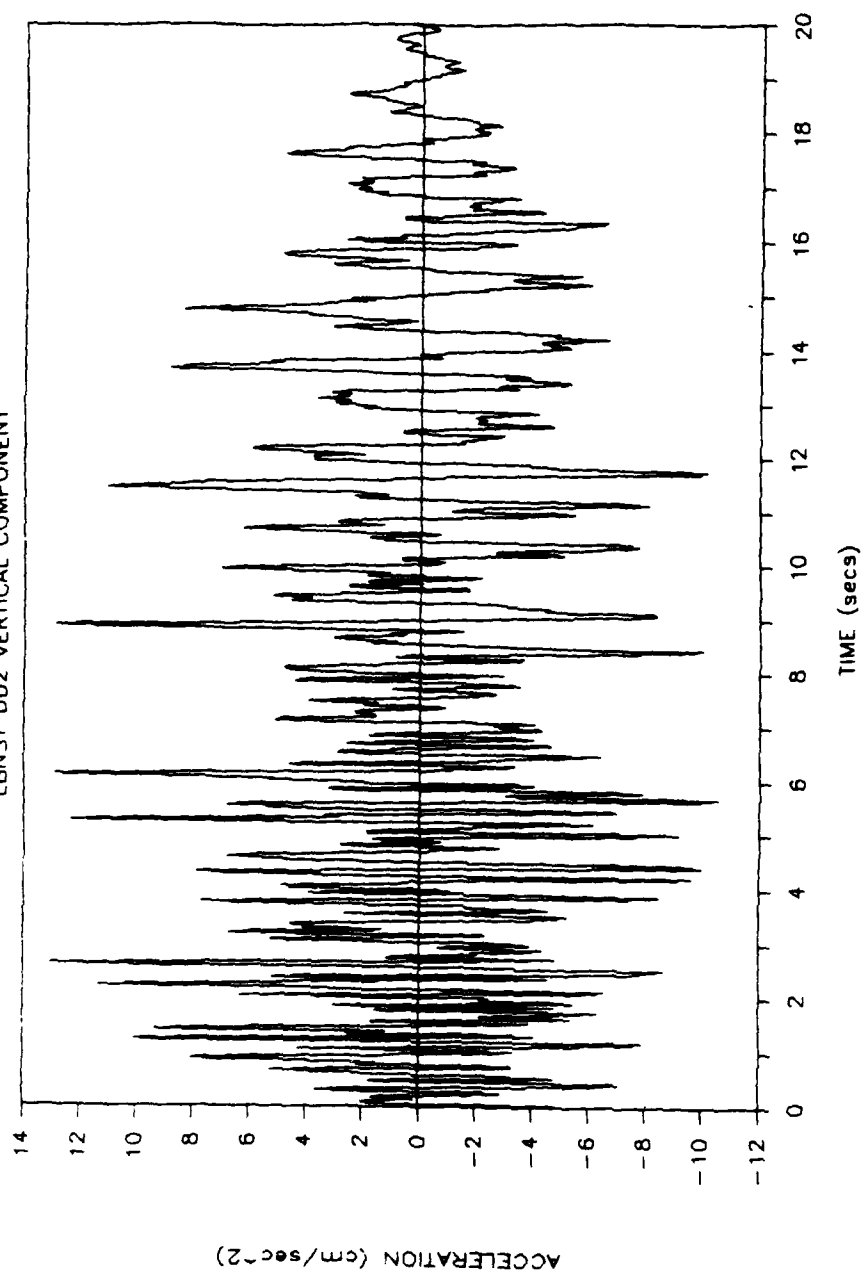


FIGURE 6.5

In order to make a valid comparison between the effects of using the 1940 El Centro earthquake and the dry dock # 2 acceleration time histories, the dry dock's accelerations are normalized to the El Centro's magnitudes. The energy content of an earthquake depends on the magnitude of its ground displacements and the earthquake duration [17]. The amount of energy that an earthquake imparts to a structural system depends on the earthquake's frequency content relative to the natural frequencies of the structure. It also depends on relative impedance or mobility of the structure relative to the ground. The Richter scale, which is measure of the earthquake's energy, is based primarily on the log of the earthquake peak displacement.

To normalize the dry dock # 2 earthquake, the first step is to make the two earthquakes' acceleration time histories the same duration, 20 seconds. The El Centro earthquake is truncated by using the first 20 seconds, the most violent part of the earthquake. The dry dock # 2 acceleration time history was originally approximately 16 seconds in duration. To create a 20 second duration, the last four seconds of the record is multiplied by an exponential decay factor and added on to the end of the existing record.

Next, the dry dock # 2 accelerations are normalized to the same magnitude of El Centro by multiplying by a factor of 10.97. This factor is obtained by dividing the peak

displacement of the El Centro earthquake (14.61 cm) by the peak displacement of the dry dock # 2 earthquake (1.33 cm).

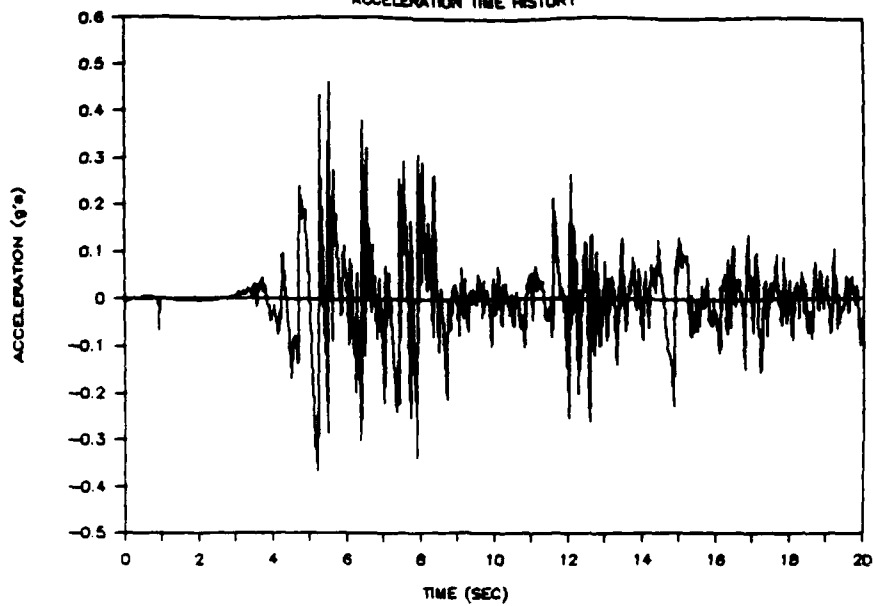
Figure (6.6) shows the 1940 El Centro earthquake acceleration time history and the normalized dry dock # 2 acceleration time history. It is clear from these plots that the excitation frequency of the normalized earthquake is much lower than that of the El Centro. These two earthquake acceleration time histories are used in this thesis for system design development.

It is clear from previous analysis that both a low stiffness design approach using isolators and a high stiffness design approach using wale shores are both viable. Using a higher frequency earthquake like the El Centro is a more conservative approach for a high stiffness design. Similarly a lower frequency earthquake like the normalized dry dock # 2 accelerations is a more conservative approach for a low stiffness design.

Figures (6.7) and (6.8) are the response (or shock) spectra for the dry dock # 2 and the 1940 El Centro [7] acceleration time history respectively. These figures show the dominant frequencies of these earthquakes. El Centro's dominant frequency is approximately 2 HZ for the 5 % damping case used in this thesis. For dry dock # 2 this dominant frequency is approximately 1 HZ again using 5 % damping.

# 1940 EL CENTRO EARTHQUAKE

ACCELERATION TIME HISTORY



# NORMALIZED DD2 EARTHQUAKE

ACCELERATION TIME HISTORY

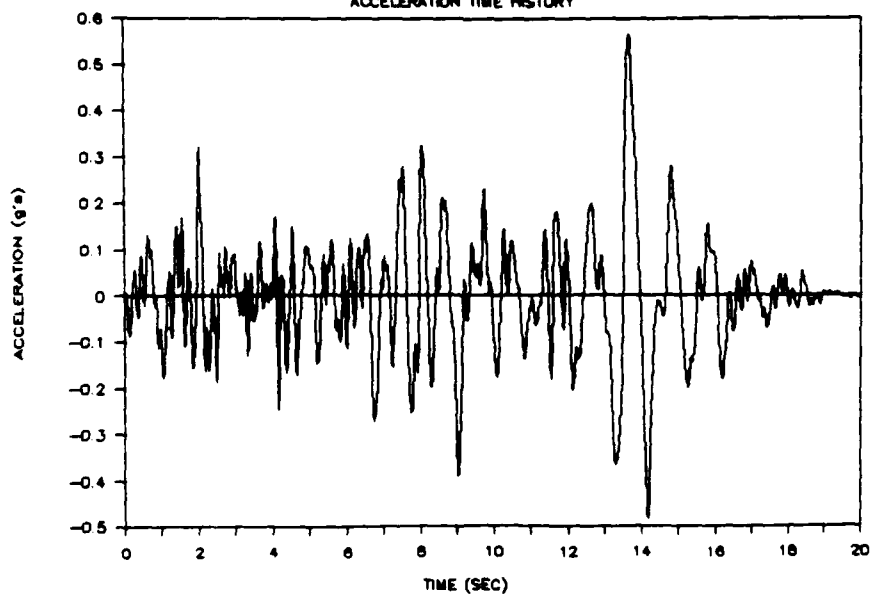


FIGURE 6.6

# RESPONSE AND FOURIER SPECTRA WHITTIER EARTHQUAKE OCT 01, 1987 -1442 GMT

111DD200 87.101.0 COMP TRAN

DD2 LBNSY

ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN .300-.400 AND 25.00-27.00 CYC/SEC.

DAMPING VALUES ARE 0, 2, 5, 10 & 20 % OF CRITICAL

— RESPONSE SPECTRA: PSV, PSA & SD — — — FOURIER AMPLITUDE SPECTRUM: FS

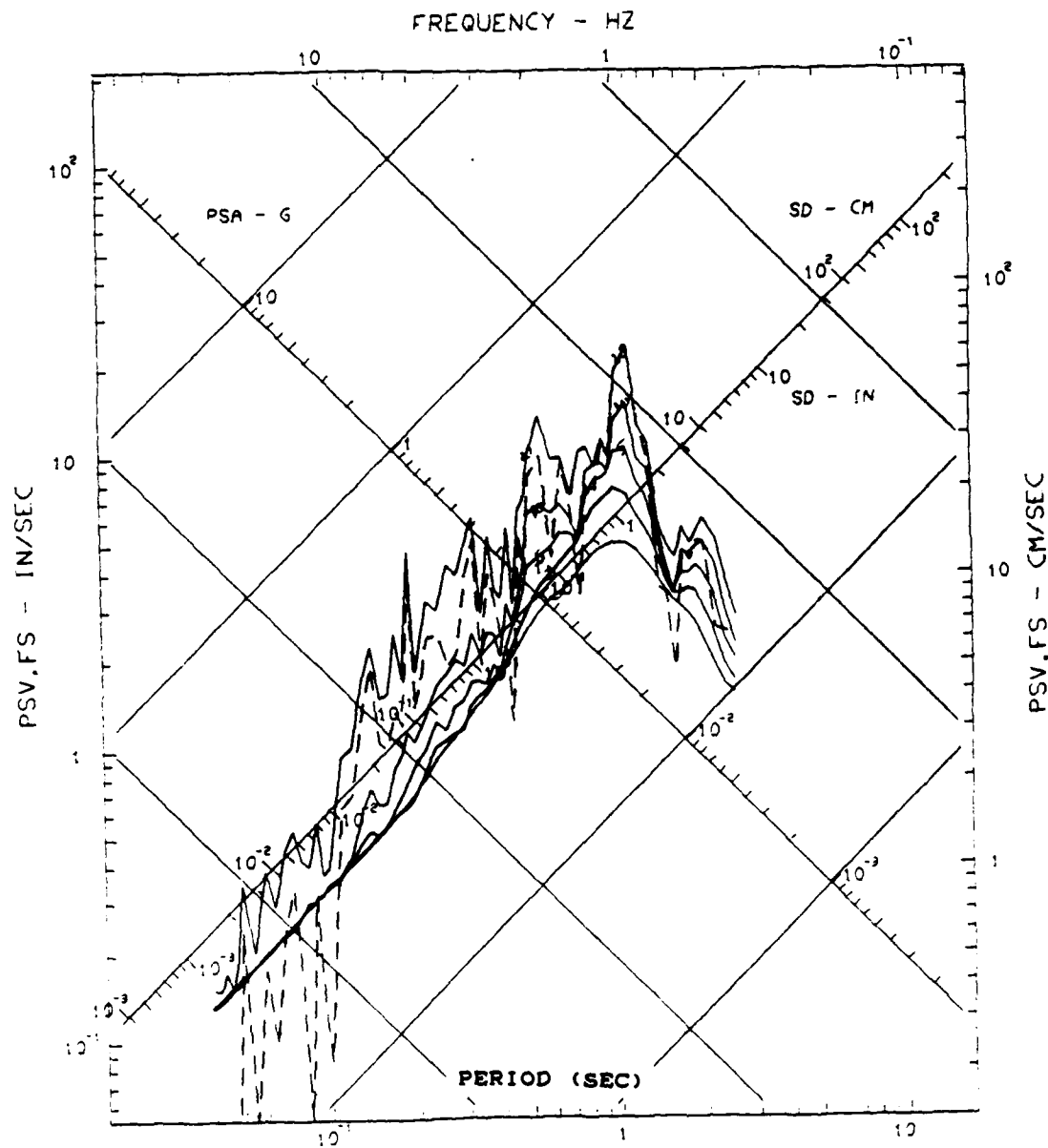
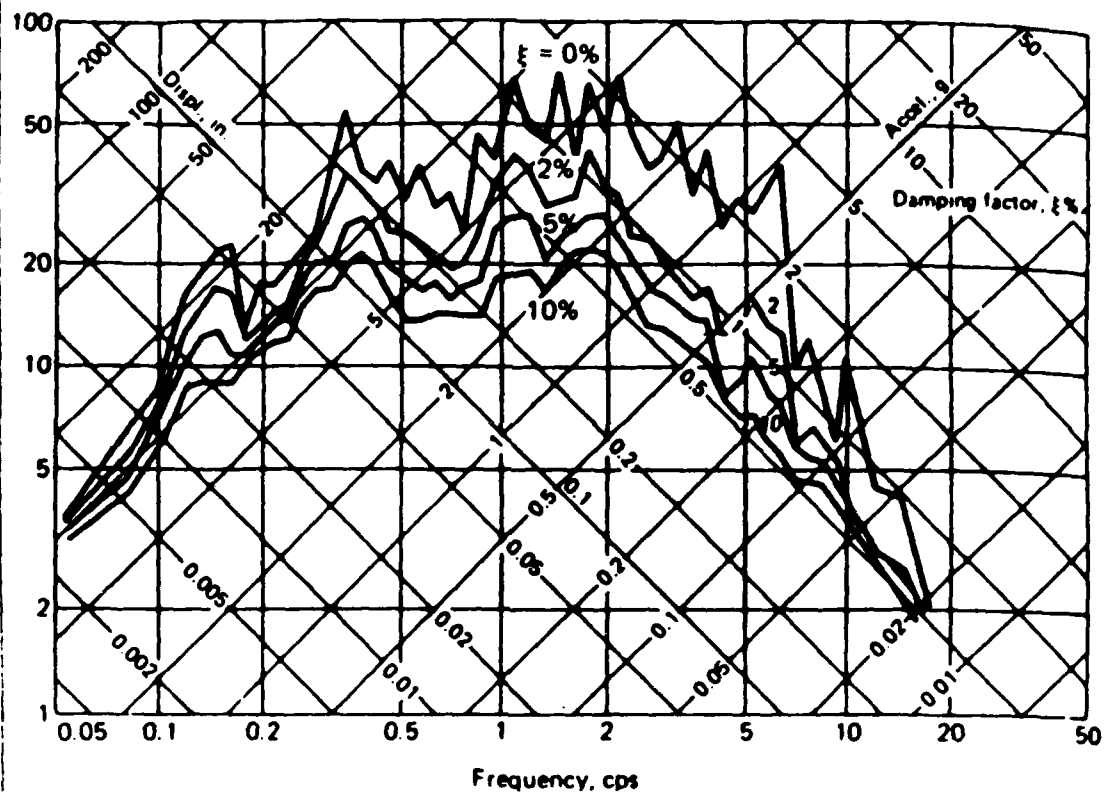


FIGURE 6.7





Response Spectra  
1940 El Centro Earthquake

FIGURE 6.8

## 6.2 System Survivability Frequency Dependence

To determine the dependence of system survivability on system natural frequency, a plot is made, figure (6.9), showing El Centro earthquake survivability versus mode 1 (fundamental) frequency. All eleven systems' mode 1 frequencies using Sigman's, bilinear, linear, and 1 inch rubber cap models are plotted. The natural frequencies for these systems range from 0.4 to 1.6 HZ with an average around 1 HZ.

There is no correlation between mode 1 frequency and earthquake survivability for these systems as shown by the data and the flat best fit line. This is because the mode 1 frequency, the lowest system modal frequency, is sufficiently below the dominant frequency of the El Centro earthquake, 2 HZ. No dynamic amplification occurs. Significant dynamic amplification and thus lowered survivability is expected if the system modal frequency is near the earthquake's dominant frequency.

This is precisely what is found when eleven bilinear systems are excited by the normalized dry dock # 2 earthquake. Figure (6.10) is a plot of normalized dry dock # 2 earthquake survivability versus mode 1 frequency. In this case, the dominant frequency of the earthquake, 1 HZ, corresponds to the average system modal frequency.

# % FAILURE VS MODE # 1 FREQ (HZ)

INCLUDES SIGMAN,BILINEAR,LINEAR,1"RUB

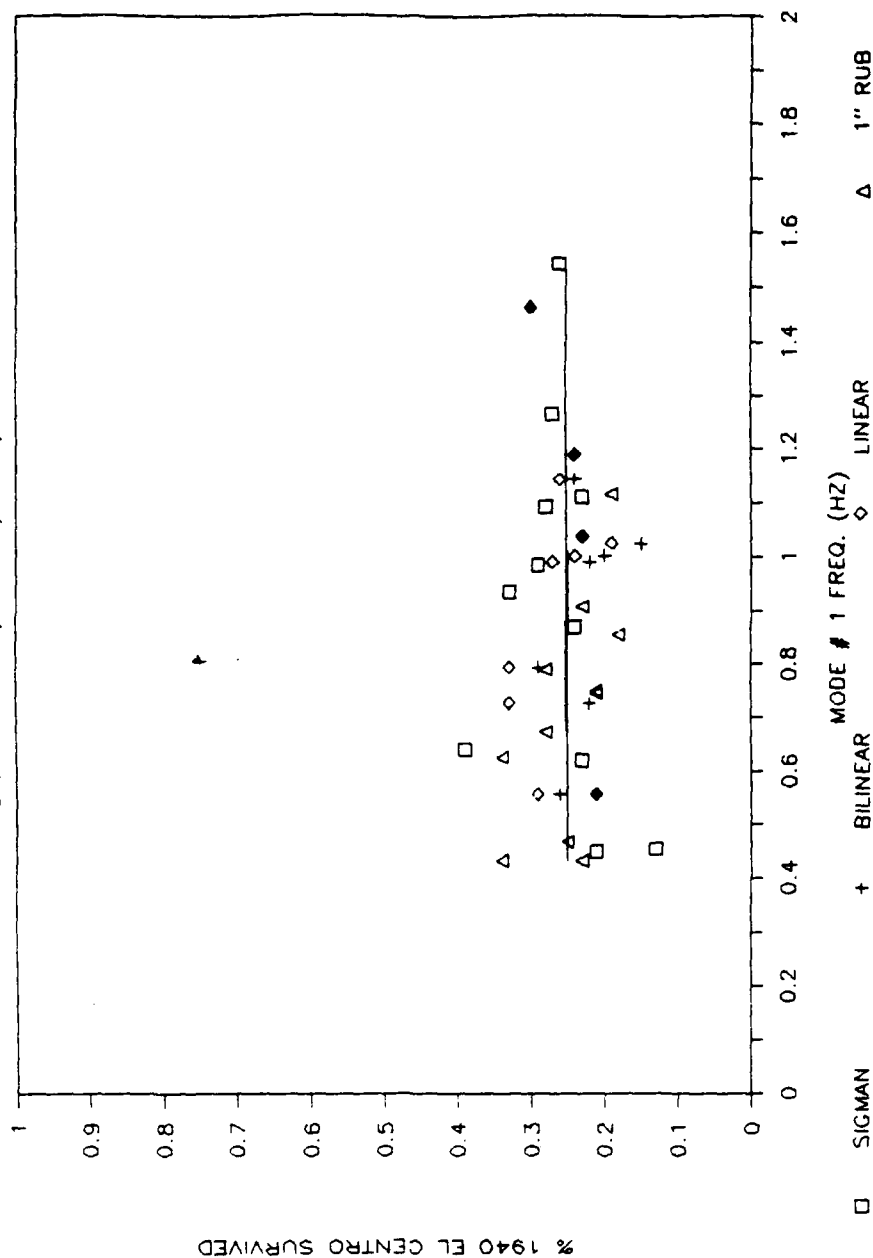


FIGURE 6.9

# % SURVIVED VS MODE # 1 FREQUENCY

NORMALIZED WHITTIER (DD2) QUAKE

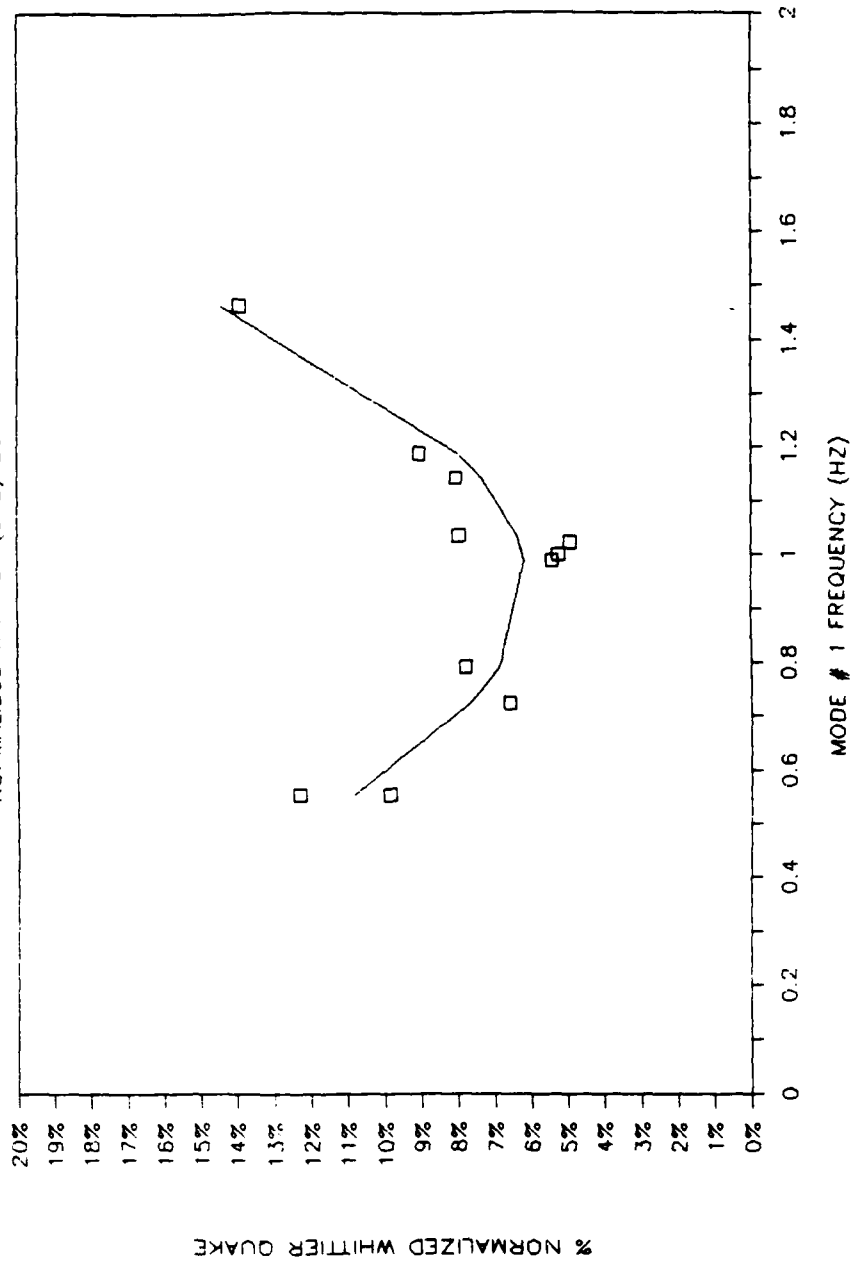


FIGURE 6.10

A clear dependence of system survivability on frequency is shown in the figure by the best fit curve. The systems with natural frequencies closest to that of the normalized dry dock # 2 earthquake has the lowest survivability.

A comparison of the survivability of the eleven submarine drydock blocking systems due to El Centro and normalized dry dock # 2 earthquakes is shown in figure (6.11). The data for this figure as well as other comparisons is included in Appendix 4. This figure clearly illustrates the degradation of system survivability due to resonant frequency effects. All eleven systems fail at much lower levels when excited by the lower frequency normalized dry dock # 2 earthquake. Overall, system survivability is about 8 % for the normalized dry dock # 2 earthquake compared with 23 % for the El Centro earthquake.

It is important to emphasize that these low survivability percentages for submarine drydock blocking systems are based on an actual earthquake acceleration time history measured in a U.S. Naval shipyard dry dock. The validity of this problem is confirmed by the *USS Leahy* case study where a current U.S. Navy ship drydock blocking system failed when subject to a relatively small earthquake (0.05 g peak acceleration). This shows the importance of taking frequency dependence into account when designing an earthquake resistant system.

# BILINEAR SURVIVAL % COMPARISONS

EL CENTRO VERSUS NORMALIZED DD2

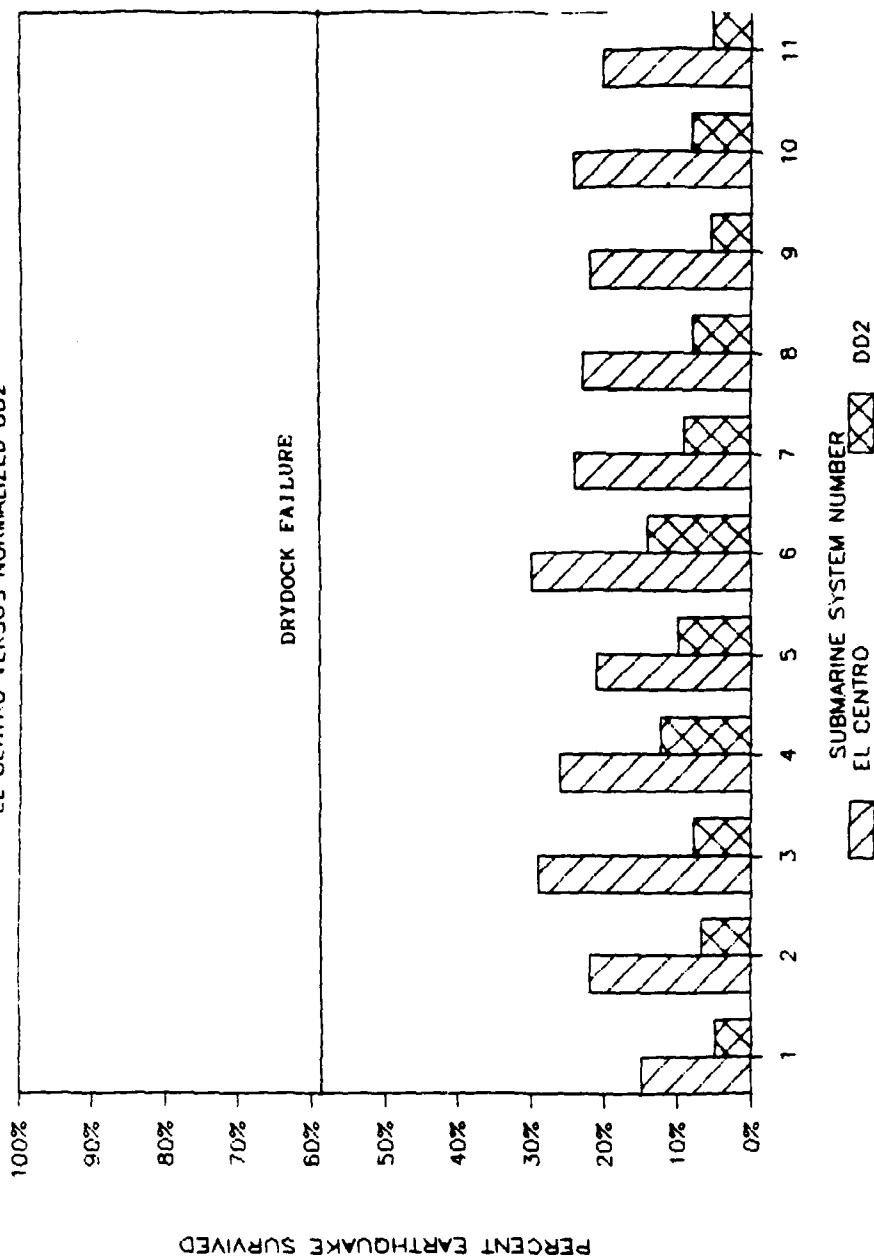


FIGURE 6.11

## CHAPTER 7

### ISOLATOR AND RUBBER LOW STIFFNESS DESIGN

#### 7.0 Design Process

Dynamic isolators and rubber caps either singly or in combination are very attractive potential solutions to the submarine drydock blocking system survivability problem. Hepburn [1] studied the properties of Dynamic Isolation Systems Inc. (D.I.S.) dynamic isolators and developed a bilinear model to describe their behavior. Using the "3DOFRUB" program with the "BILINALL" and "RUBBER" subroutines, a design study of a blocking system with D.I.S. isolators and rubber caps is undertaken. The purpose of this study is to find a low stiffness system which survives up to dry dock failure (0.26 g's).

The first step in the study is to install D.I.S. isolators in place of the oak layer in submarine blocking system # 1, the SSBN 616 system used by Hepburn [1]. The isolator parameters are the same as Hepburn's. In addition, one inch of natural rubber is added to the top of the Douglas fir cap. The 1940 El Centro earthquake is the exciting earthquake for the initial portion of this study.

The first result is unexpected. Using the D.I.S. isolators without a rubber cap, Hepburn found that the system

survives 35 % of the earthquake. With one inch rubber cap without isolators, system # 1 survives 32 %. It was expected that the combination would increase survivability. Actually it is found that this combination resulted in lower (20%) survivability.

In general, this decrease is due to the effect of multiple modes of vibration. By using either 1 inch rubber caps or D.I.S. isolators singly, the system's mode 1 frequency is driven well below the fundamental frequency of the El Centro Earthquake. At the same time, the system's mode 2 frequency is driven lower but still remains well above the earthquakes fundamental frequency.

By combining the rubber and isolators, the mode 1 frequency is driven very low, but the mode 2 frequency is driven into resonance. From this it became clear that to develop a successful design, both the mode 1 and 2 system frequencies must be driven well below resonance without driving mode 3 into resonance. While mode 1 and 2 are coupled, mode 1 is primarily the system's rotation, and mode 2 is primarily horizontal displacement. Mode 3 is the system's vertical displacement.

Using "3DOFRUB", several runs are made with progressively less horizontally stiff isolators. To reduce horizontal stiffness the values of  $khs$ ,  $khk$ ,  $khsp$ ,  $kkhp$ , and the



associated QD values are decreased. Figure (7.1) is plot of the 1 inch rubber cap/isolator system survivability versus mode 2 frequency. The figure shows that as the systems frequency and horizontal stiffness is decreased, system survivability increases dramatically. The mode 2 frequency is being driven below the earthquakes fundamental frequency.

Figure (7.1) shows that the system survives a 0.26 g earthquake, however, the horizontal stiffness required is reduced by 60 % from the original rubber/isolator horizontal stiffness. To actually construct a system with this horizontal stiffness would require isolators with extremely low horizontal stiffness. These isolators may be impractical to fabricate.

To allow the isolators to have higher horizontal stiffness the effects of using thicker rubber caps is explored. Figure (7.2) is a comparison of system survivability using various rubber cap thicknesses. The use of 3 inches of rubber does not significantly shift the survivability curve toward higher stiffnesses. Therefore, the use of 6 inch rubber caps is investigated. Six inches is considered the practical thickness limit. Rubber caps thicker than this would tend to be vulnerable to wind loads, but the wind load problem is not investigated in this thesis.

# % SURVIVED 1940 EL CENTRO FOR 1" RUBBER CAPS W/ ISOLATORS

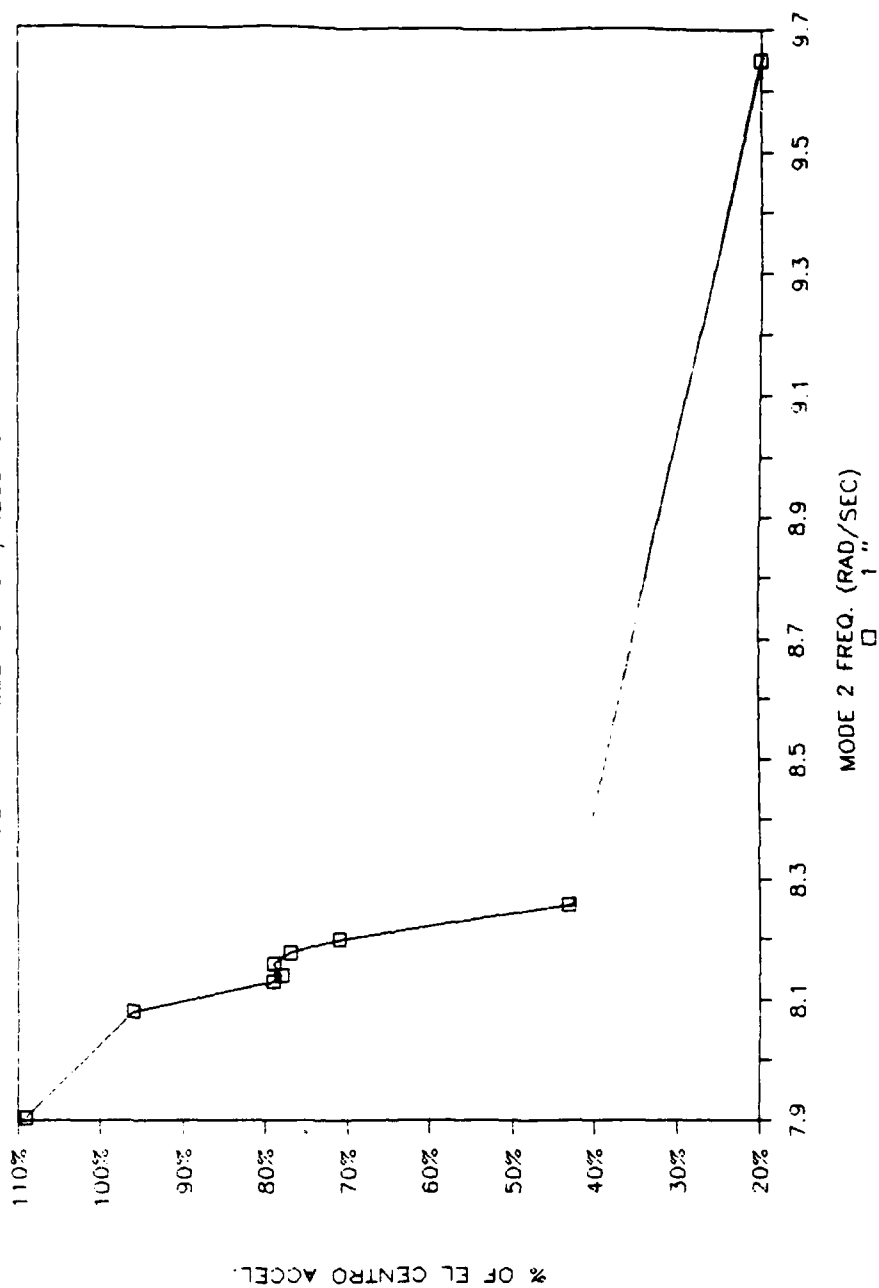


FIGURE 7.1

# % SURVIVED 1940 EL CENTRO FOR VARIOUS RUBBER CAPS W/ ISOLATORS

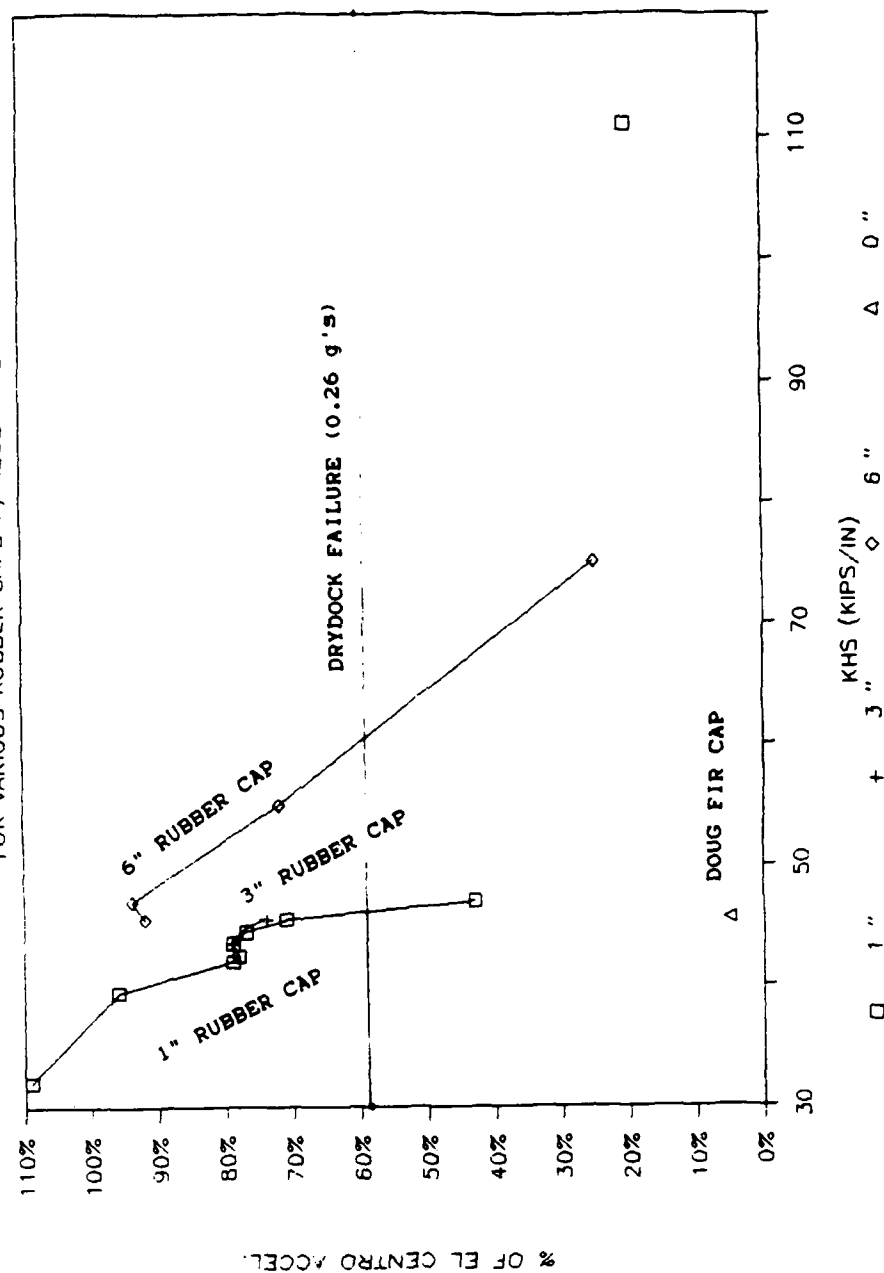


FIGURE 7.2

The use of six inches of rubber significantly shifts the survivability curve to the right as seen in figure (7.2). Therefore, six inches is selected for the final low stiffness design solution. Figure (7.3) is a comparison between the various rubber cap thicknesses for a given horizontal stiffness. This shows the additional benefits of the use of rubber caps. Increasing the thickness of the rubber improves survivability by preventing liftoff.

The use of at least one inch of rubber cap is vital. Survivability jumps from 5% to 70% with the use of just one inch of rubber. The side block horizontal stiffness used for the figure (7.3) comparison is the final design stiffness used. The figure shows that if the rubber cap is removed the system would survive a much smaller earthquake than the original system # 1. However, the rubber caps alone cannot provide a low enough horizontal stiffness to survive up to dry dock failure. The final low stiffness solution using the 1940 El Centro earthquake survives 72 % (0.32 g's). The data file and output from "3DOFRUB" for this solution is included in Appendix 5.

Since the normalized dry dock # 2 earthquake has a lower fundamental frequency, this earthquake is used to test the low stiffness solution. It is found that the horizontal stiffness has to be decreased even further for the system to survive the 0.26 g dry dock survival level.

# EFFECT OF USING RUBBER CAPS & ISOLATORS

WITH KHS 45.5 KIPS/IN

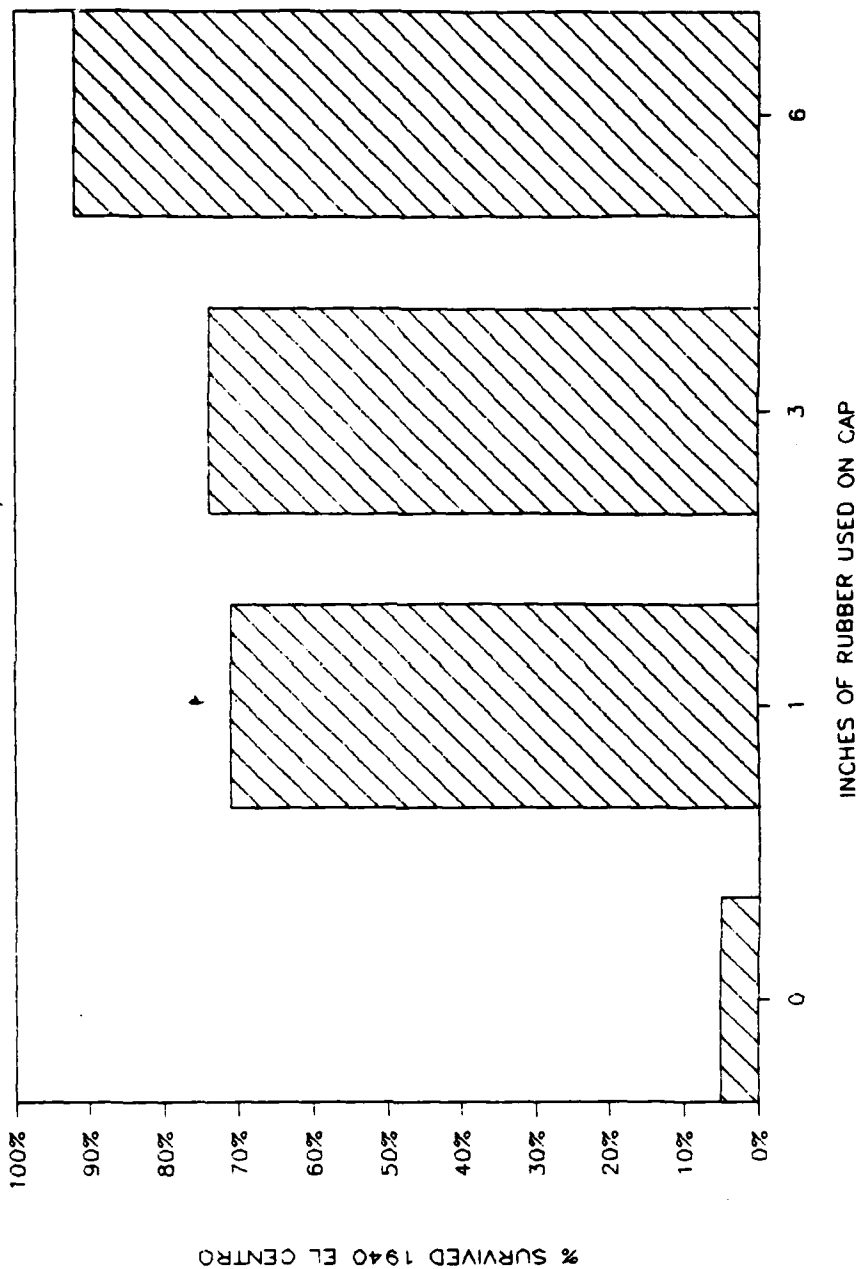


FIGURE 7.3

The final survival level is 0.28 g's (63%). This new low stiffness solution is recommended if the rubber/isolator method is used.

From this solution, the parameters of the required individual dynamic isolators has to be determined. This is accomplished by using the blocking pier stiffness spreadsheets included in Appendix 5. These are the same spreadsheets as used to calculate the blocking pier stiffnesses. They are used to calculate the individual isolator properties by working backwards.

The isolators' parameters are determined as follows. First, the spreadsheet for determining blocking pier horizontal stiffness is used. Knowing the pier's overall stiffness and dimensions and knowing the properties of all the other layers, the only parameter that could be varied to give the proper total pier stiffness is the isolator's modulus of elasticity,  $E$ . By varying  $E$  until the correct pier stiffness is obtained, the correct value of  $E$  for the isolator is obtained. Next, to determine the horizontal stiffness of an individual isolator, all the other blocking pier layers are made infinitely stiff except for the isolator. With the isolator  $E$  value known, the value of individual isolator stiffness is given by the spreadsheet. This procedure is used to determine first stiffness line (elastic) and second

stiffness line (plastic) isolator parameters for both the keel and side block systems.

The QD values for the isolators are determined using the following equation:

$$QD = XEL * (KU - KD) \quad (7.1)$$

where:

XEL is the elastic limit for the original isolator, used by Hepburn [1], in inches.

QD is the restoring force intercept of the second stiffness slope for the isolator.

KU is equal to the elastic stiffness of the isolator.

KD is equal to the plastic stiffness of the isolator.

Table 7.1 are the original isolator parameters used by Hepburn [1]. Using the same XEL values as the original isolators the value of QD is determined by applying equation (7.1).

TABLE 7.1  
ORIGINAL D.I.S. ISOLATOR  
PARAMETERS

	SIDE ISOLATOR	KEEL ISOLATOR
XEL:	0.285 in	0.400 in
QD:	4.55 kips	11.03 kips
KU:	17.8 kips/in	31.31 kips/in
KD:	1.83 kips/in	3.72 kips/in
Kvert:	850 kips/in	1845.83 kips/in

(where Kvert is the vertical stiffness of each isolator)

TABLE 7.2  
FINAL LOW STIFFNESS DESIGN ISOLATOR  
PARAMETERS

	SIDE ISOLATOR	KEEL ISOLATOR
XEL:	0.285 in	0.400 in
QD:	0.638 kips	1.15 kips
KU:	2.75 kips/in	3.36 kips/in
KD:	0.51 kips/in	0.49 kips/in
Kvert:	850 kips/in	1845.83 kips/in



The manufacturer (D.I.S.) of the isolators was contacted once the parameters of the required isolators were known. D.I.S. Vice President for Engineering, Buckle [18], stated that an isolator with these required parameters would be impractical to build. However, he stated that an isolation system of equivalent properties could be built using higher stiffness isolators on every fourth block.

The blocks without isolators would have low friction sliders which carry the vertical load and provide no horizontal stiffness. These sliders would be coated with a low friction material such as teflon. Such sliders, according to Buckle, are used extensively in bridge isolation systems. The final low stiffness solution does incorporate sliders.

## 7.1 Description of the Low Stiffness Solution

Figure (7.4) is a 2D drawing of the recommended low stiffness submarine drydock blocking system solution. This solution survives 63 % (0.28 g's) of the normalized dry dock # 2 earthquake. The design includes the following features:

1. Isolators will be placed in every fourth keel and side blocking pier. All other blocking piers will contain sliders.
2. All keel and side block piers are rigidly attached to the dry dock floor to prevent overturning.
3. A steel carriage is used to rigidly tie the caps together transversely to prevent sliding. It also ties the system together longitudinally so the isolators provide a restoring force to entire system.
4. The steel carriage is only rigidly attached to the blocking piers containing isolators. It is free to slide on all other piers.
5. A 6" rubber cap is used on top of the steel carriage to help prevent liftoff and to aid the isolators in decoupling the submarine from ground acceleration.

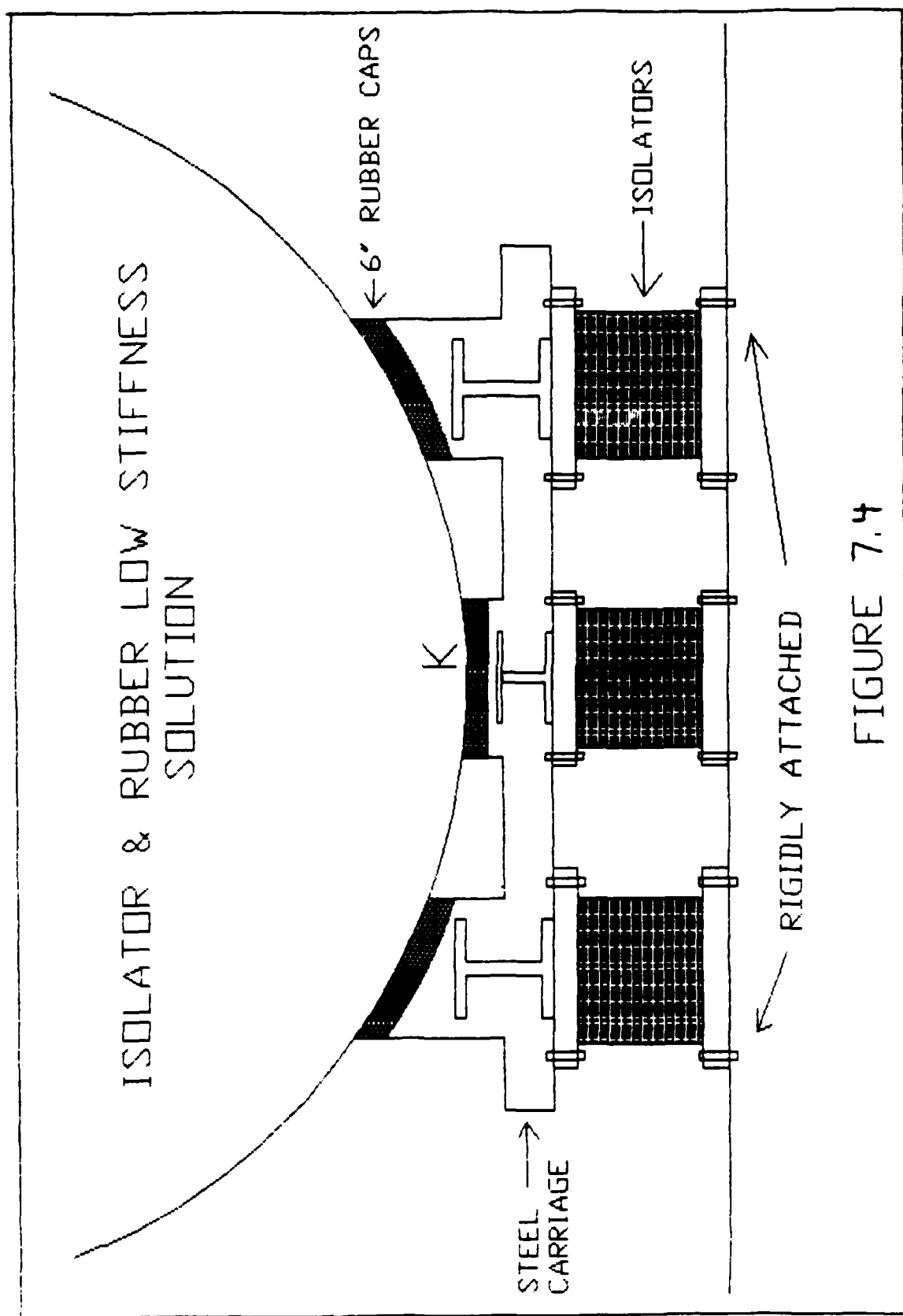


FIGURE 7.4

The "3DOFRUB" program could not completely model this system directly. Therefore, a few changes to the data file are required to simulate this system. First, the keel and side block widths are made extremely wide to simulate rigid attachment. The block on block friction coefficient is made extremely high to simulate the caps' rigid attachment to the steel carriage. The model used has the isolators attached to concrete blocks instead of to the dock floor; however, the stiffness of the isolators is so low compared to the concrete that this has no effect on the results.

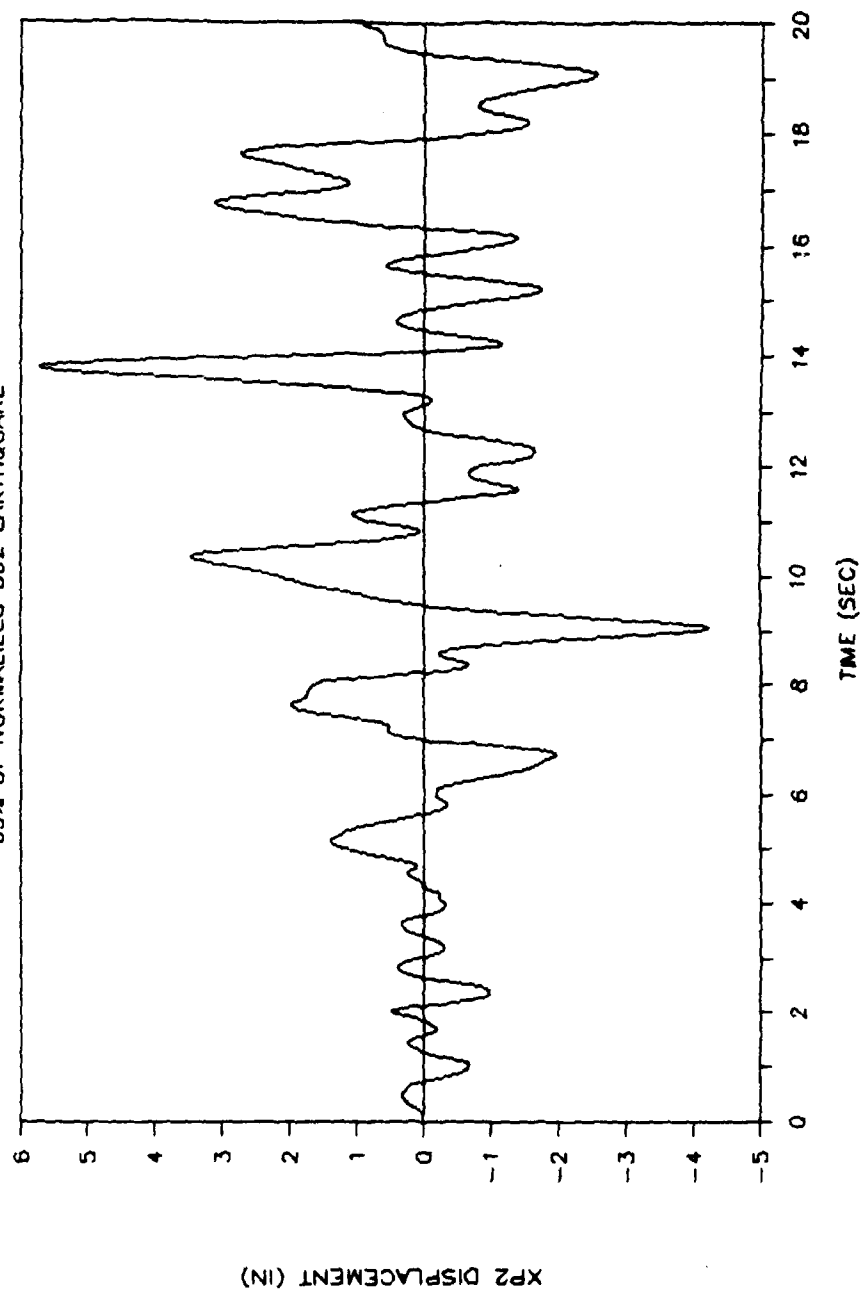
## 7.2 Response of the Low Stiffness Solution

The response plots analyzed in this section for the low stiffness solution are due to excitation by 63 % of the normalized dry dock # 2 earthquake. The natural frequencies of the low stiffness solution are such that the lower frequency normalized dry dock # 2 earthquake produced lower levels of survivability, 63%, compared to the higher frequency 1940 El Centro earthquake, 72%. The normalized dry dock # 2 earthquake was used to produce the output plots because it had lower frequencies and produced a lower level survivability; therefore, it was the more conservative earthquake to use in analyzing the low stiffness design.

Figure (7.5) is a plot of the keel horizontal displacement relative to the dry dock floor as a function of time. This plot shows that the low stiffness solution has very large horizontal relative displacements associated with it. The maximum keel displacement seen in this figure, about 6 inches, is typical for base isolated structures according to Buckle [18]. The displacements are large; however, they have a low frequency and are smooth which means the submarine is experiencing low velocities and accelerations. This horizontal displacement response is extremely different from that of the exciting acceleration shown in figure (6.6). This illustrates the horizontal decoupling effect of the rubber/isolator systems.

These low accelerations can be seen in the keel block horizontal force versus time plot in figure (7.6). The high stiffness solution discussed in chapter 8 has keel block horizontal forces which are larger by an order of magnitude. Figure (7.7) shows the rotational response of this system. This figure is a plot of the systems rotation about the keel versus time. This plot shows that the rotations are relatively large, but smooth and low in frequency. This response is also extremely different from that of the exciting acceleration and shows the rotational decoupling of the rubber/isolator system. However, figure (7.8) shows that the vertical displacement is more closely coupled with the earthquake's vertical acceleration (figure (6.5)).

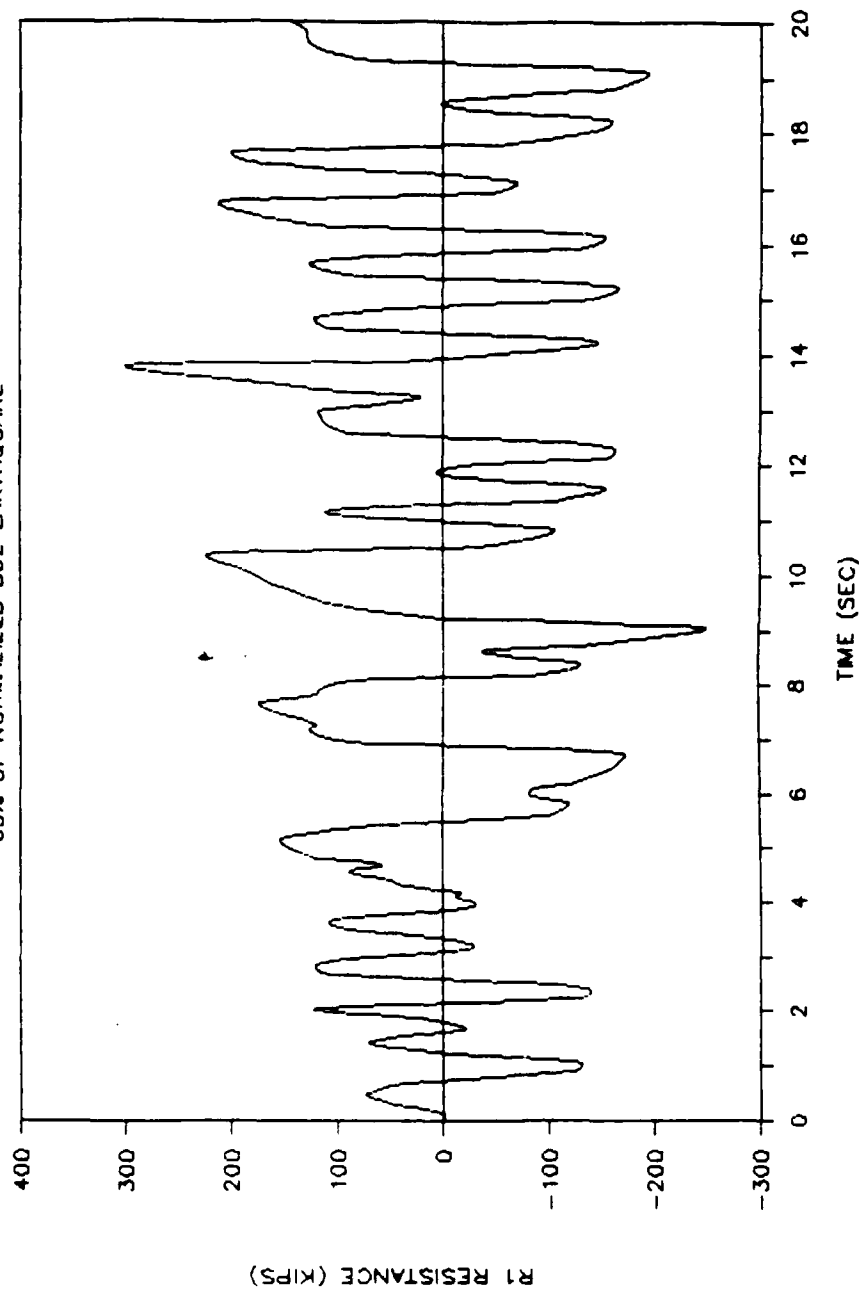
# SYSTEM #893 X1 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Horizontal Displacement  
vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.5

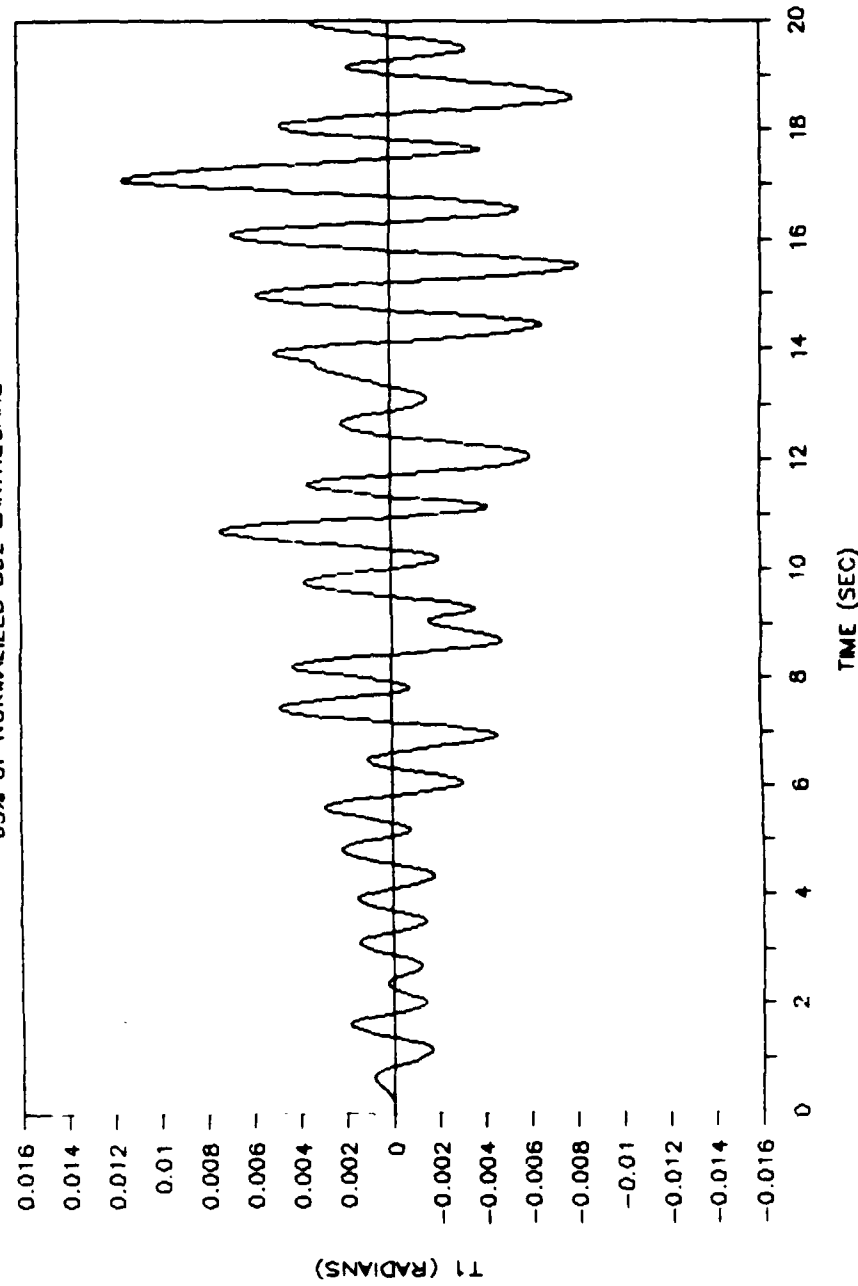
SYSTEM #893 R1 VS TIME  
63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Horizontal Force vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.6

# SYSTEM # 893 T1 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE

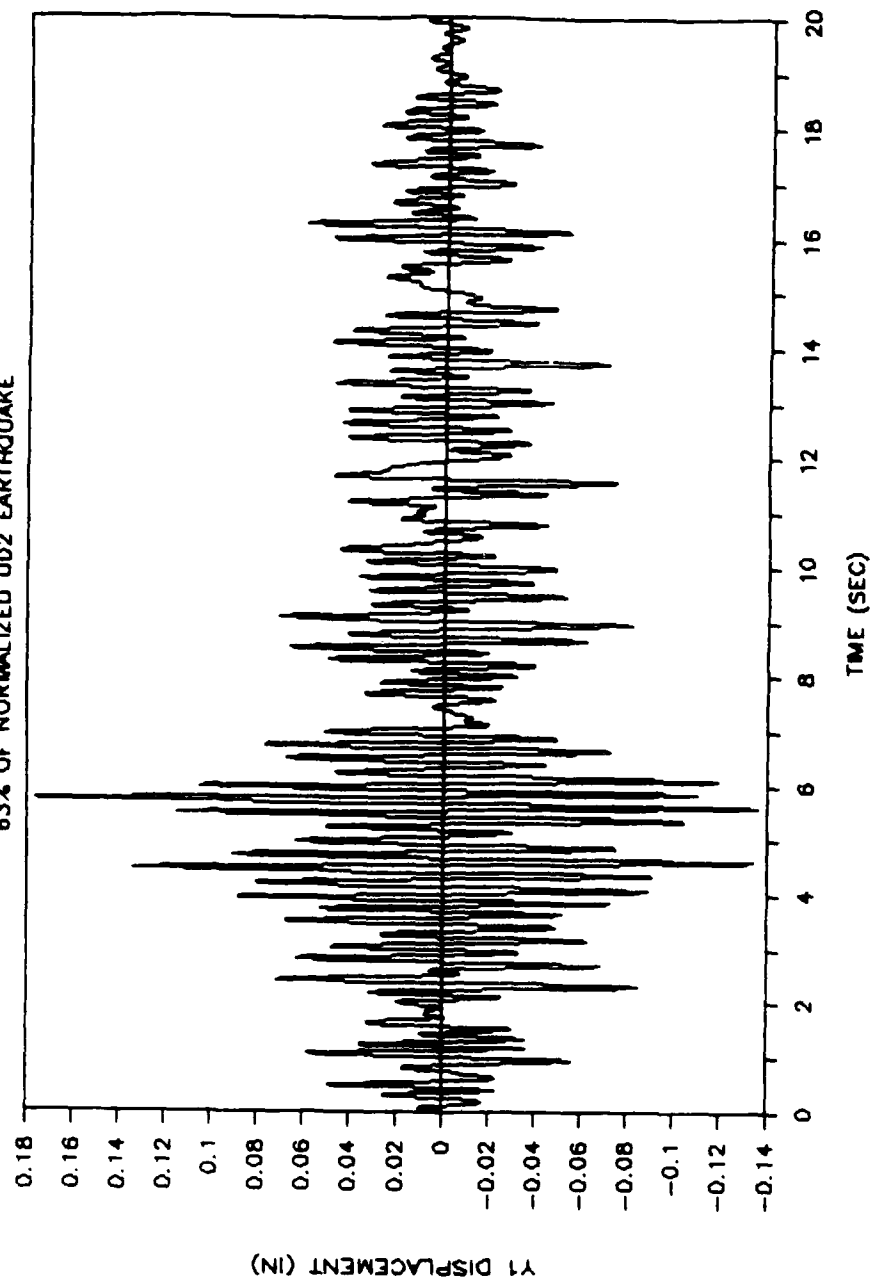


Low Stiffness Solution Rotation vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.7



# SYSTEM #893 Y1 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Vertical Displacement vs. Time  
63 % of Normalized DD2 Earthquake

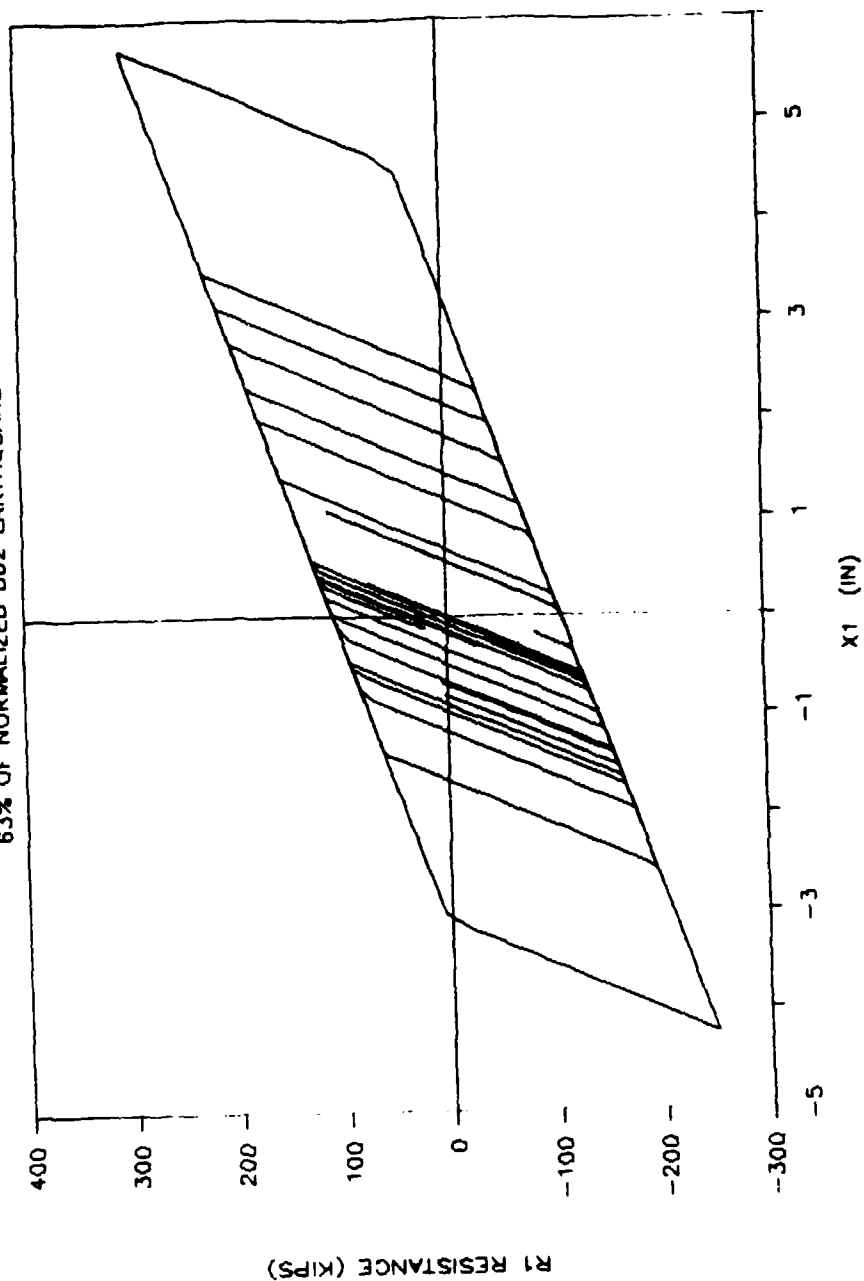
Figure 7.8

The bilinear behavior of the dynamic isolators is clearly shown in figure (7.9). This figure shows the keel restoring force versus horizontal displacement. The two stiffness slopes are evident. If during an earthquake excitation loop the isolator does not go plastic, the force oscillates up and down the elastic stiffness slope as can be seen in the figure. The total area inside all of the hysteresis loops is the amount of energy the isolator dissipates from the system during the earthquake. This hysteretical damping is one of the key benefits of using D.I.S. isolators.

The forces on the left side blocks, keel blocks, and right side blocks are shown in figures (7.10 through 7.12) respectively. The first key thing to note about these three figures is that at time zero the total force on all three blocking systems is the weight of the submarine. The keel block system's load is 12000 kips (70 %), and each side block system's load is 2300 kips (15 %).

The side block force is mostly due to rotation of the submarine as can be seen by its similarity to figure (7.7) which is the plot of system rotation. The other significant feature of the right and left side block plots is that the forces are 180 degrees out of phase which is consistent with the physical situation. The forces on the keel are due to a combination of static load and vertical displacement.

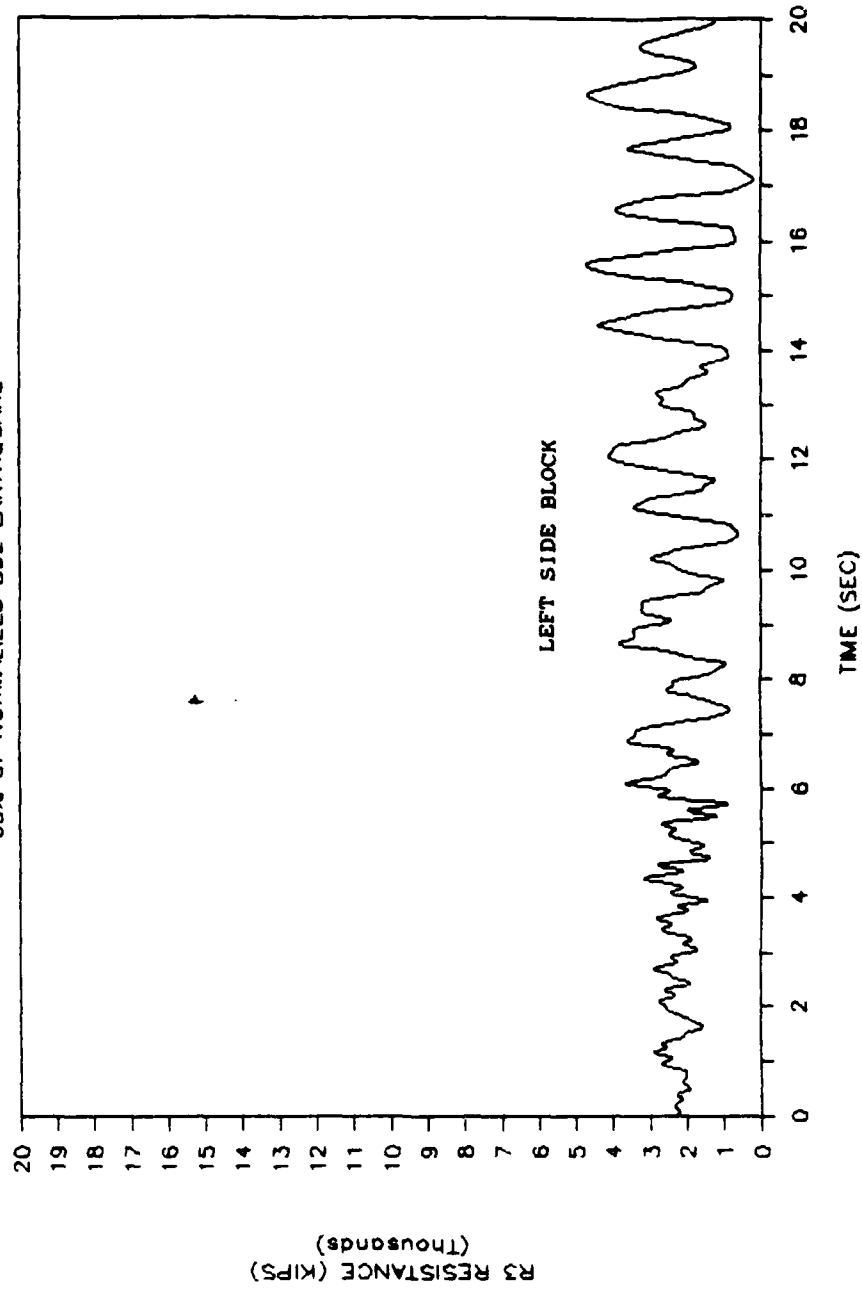
# SYSTEM #893 R1 VS X1 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Horizontal Force  
vs. Keel Block Horizontal Displacement  
63 % of Normalized DD2 Earthquake

Figure 7.9

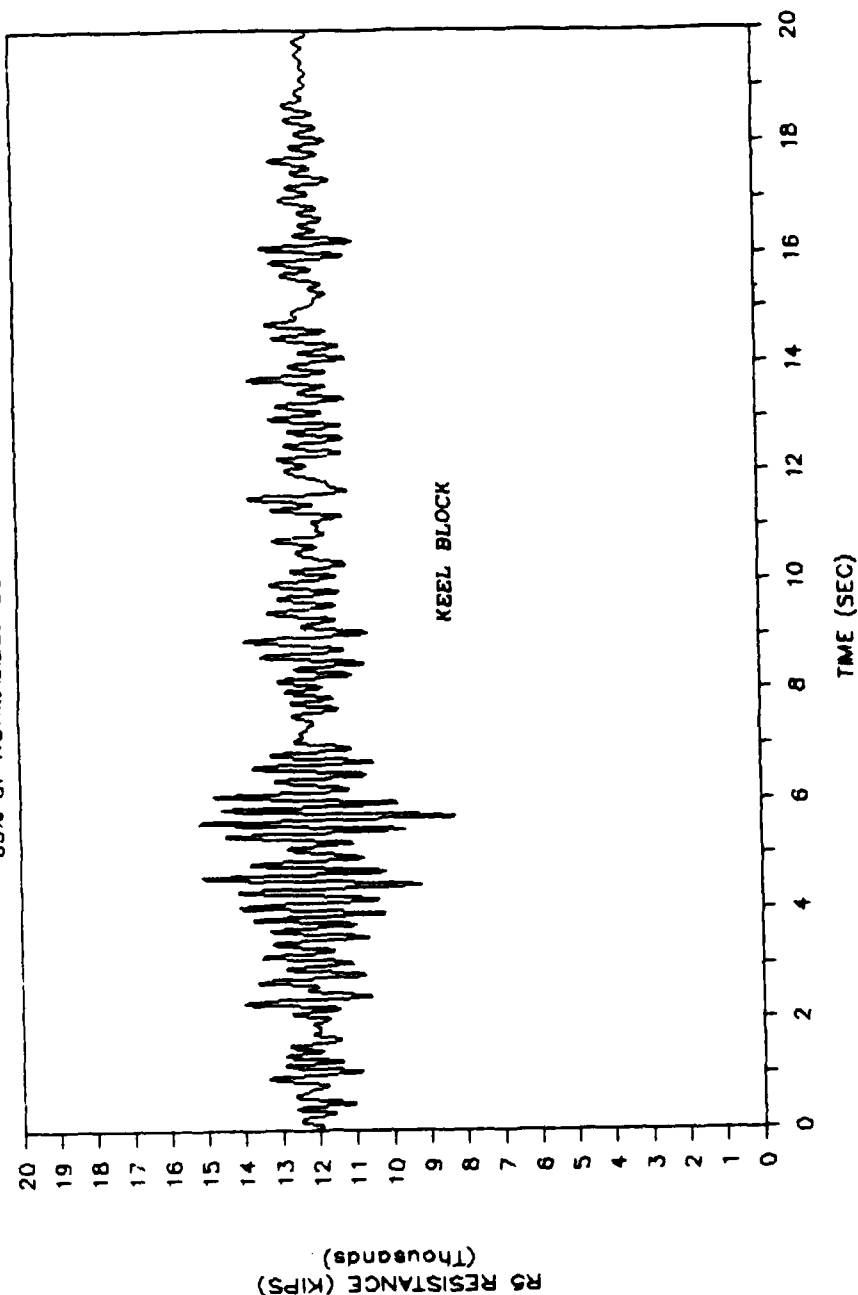
# SYSTEM #893 R3 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Right Side Block Vertical Force vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.10

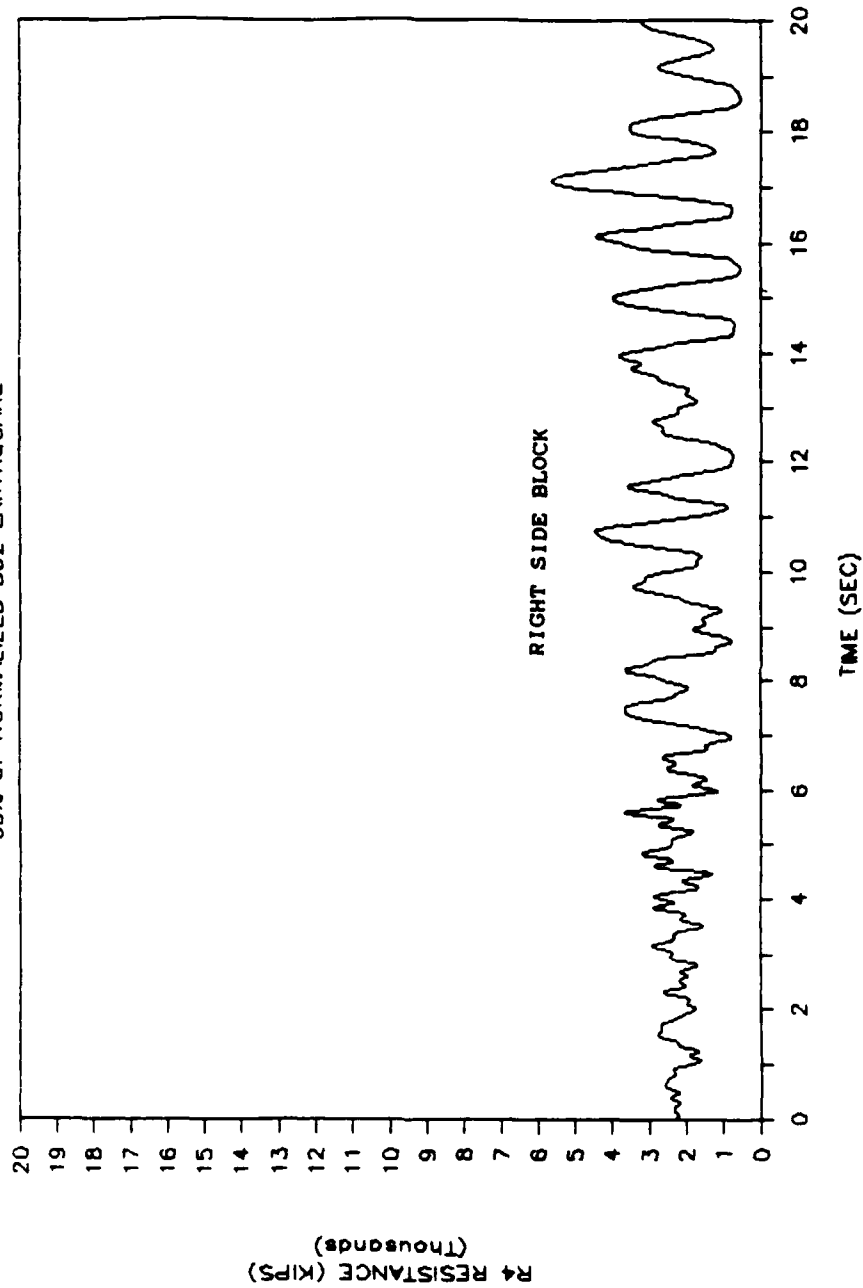
# SYSTEM #893 P5 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Vertical Force vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.11

# SYSTEM #893 R4 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



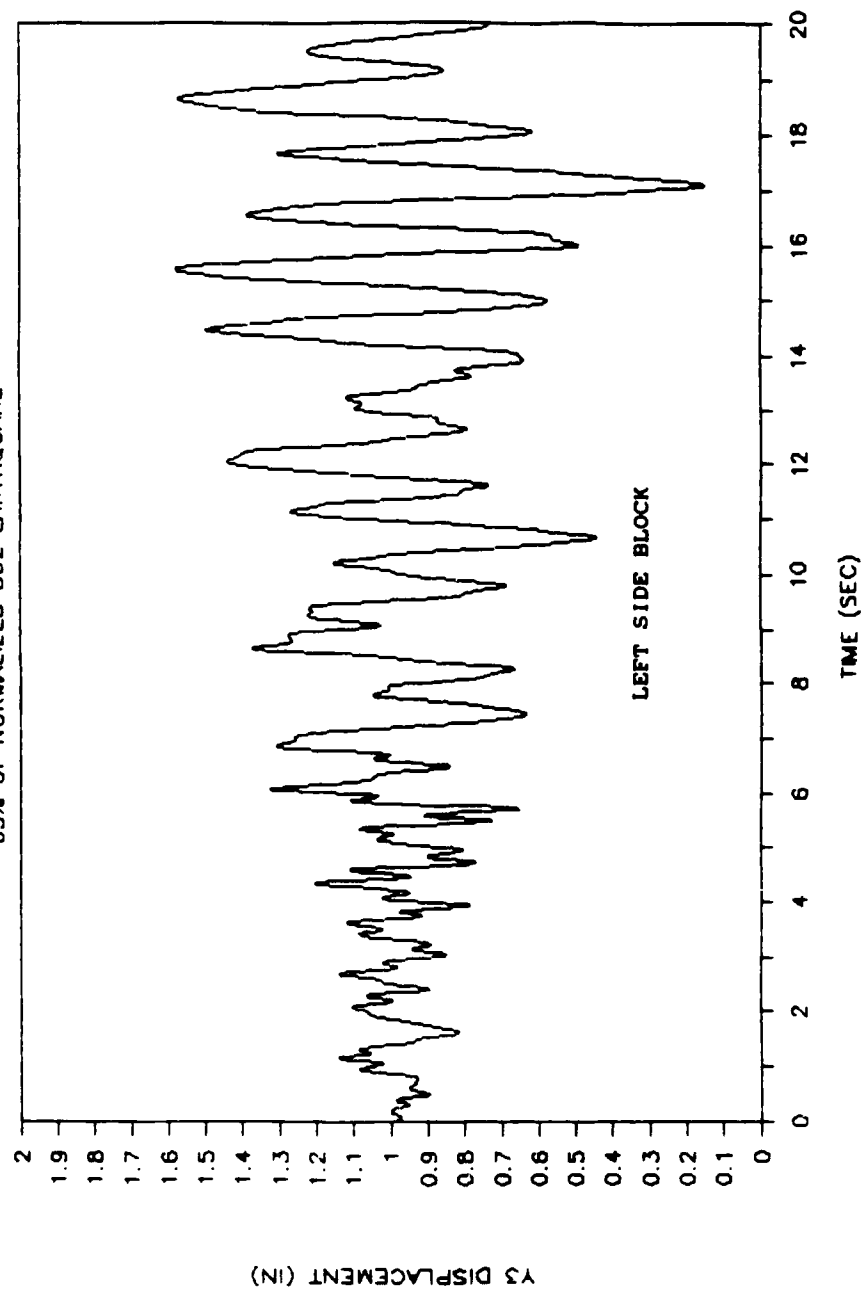
Low Stiffness Solution  
Left Side Block Vertical Force vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.12

The displacements of the left side blocks, keel blocks, and right side blocks are shown in figures (7.13 through 7.15) respectively. At time zero, the plots represent the static deflection caused by the submarine's weight. In this case all three systems initially have the same displacement. This must be the case if the submarine is assumed to be a rigid body which it is. The initial displacement is approximately one inch into the rubber cap. The plots show that liftoff does not occur; however, for the left side block system liftoff came within 0.15 inches of occurring. For the right side block the system only came within 0.4 inches of liftoff.

The differences between the right and left side block response is due to the random nature of the exciting forces. The overall range of the displacements is very close to being the same. Even though the forces experienced by the keel blocks are much higher than those on side blocks, the relative vertical displacement of the keel blocks is very small compared to the side blocks. This is because the side blocks are much less stiff vertically than the keel blocks, and the keel blocks are not subject to rotation. These plots show that the model is producing reasonable response output. They provided an excellent check of the "3DOFRUB" computer program.

# SYSTEM #893 Y3 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE

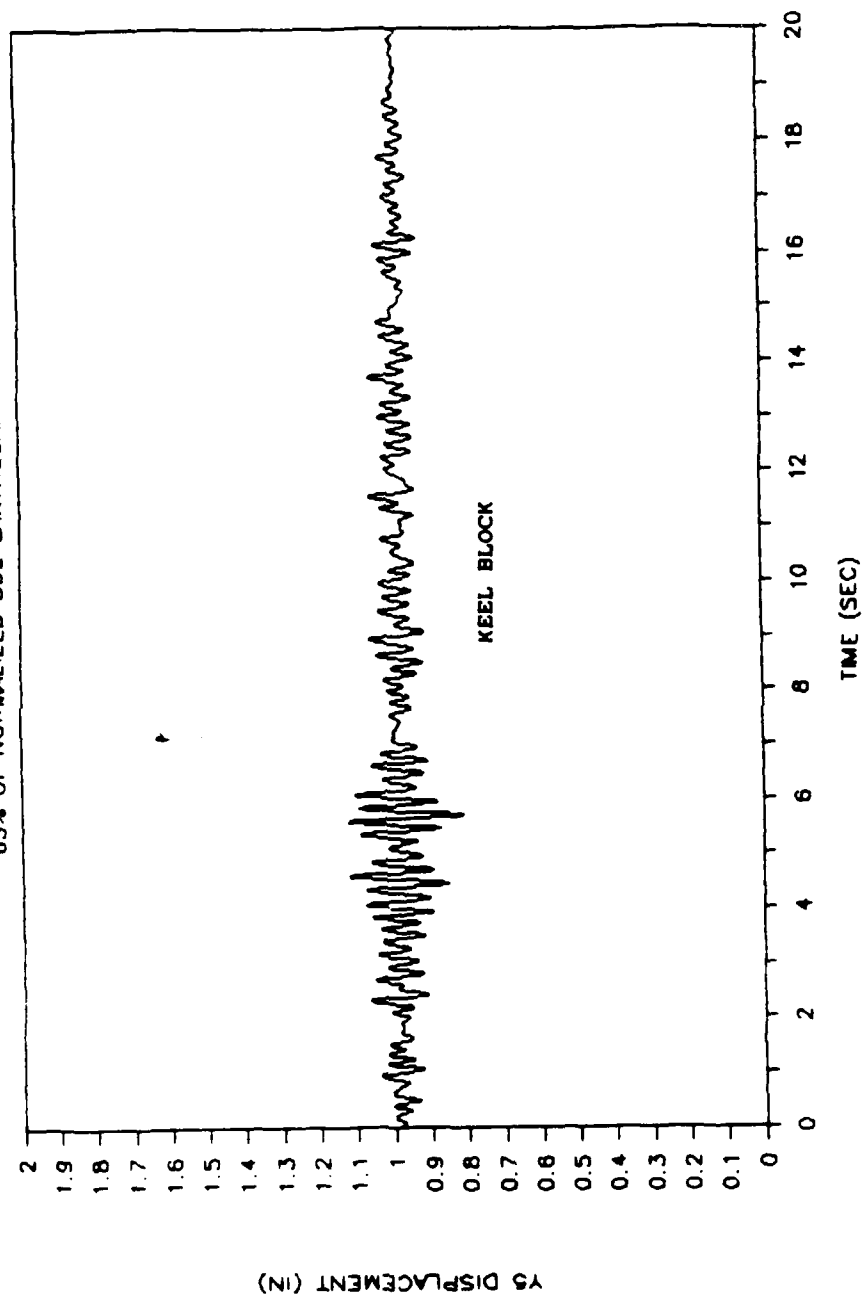


Low Stiffness Solution  
Left Side Block Vertical Displacement  
vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.13



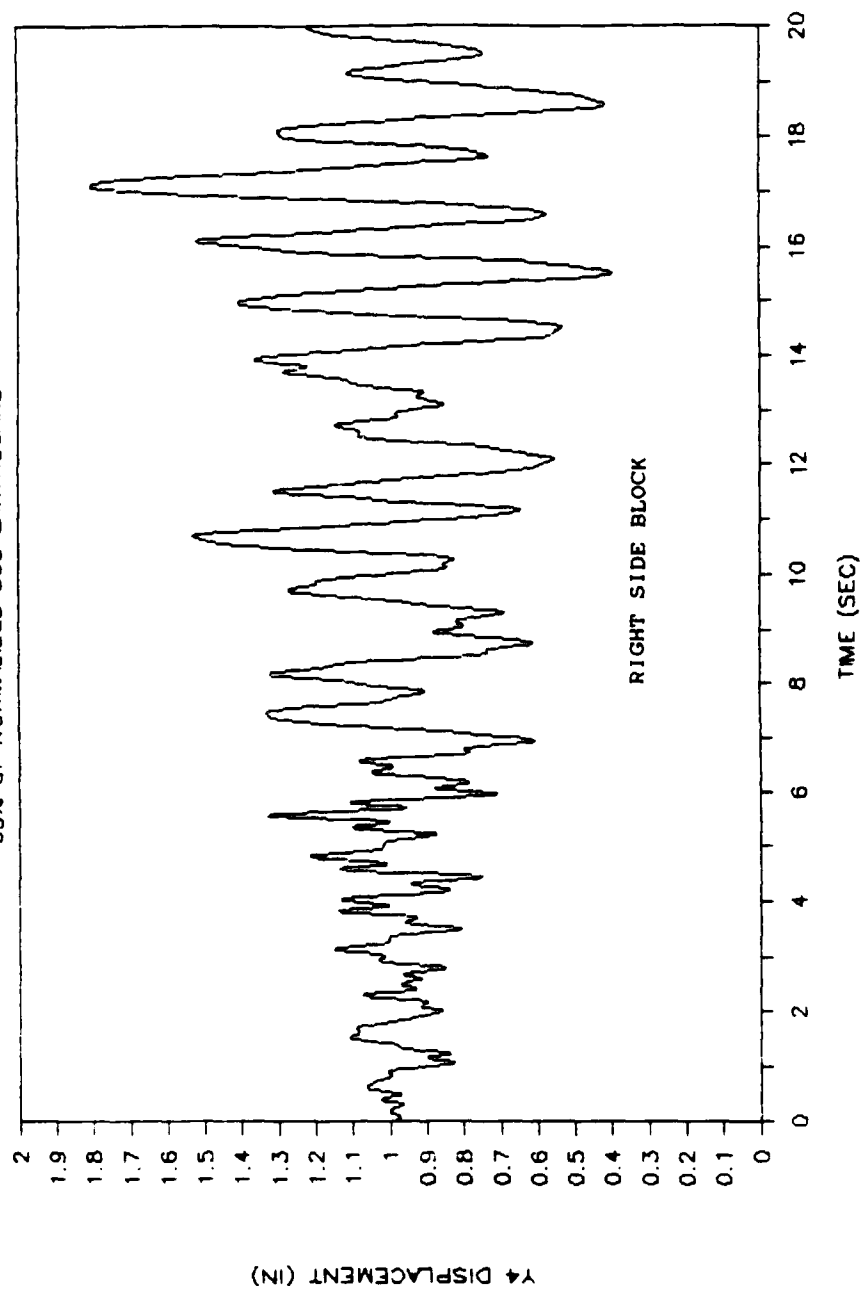
# SYSTEM #893 Y5 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Vertical Displacement vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.14

# SYSTEM #893 Y4 VS TIME 63% OF NORMALIZED DD2 EARTHQUAKE

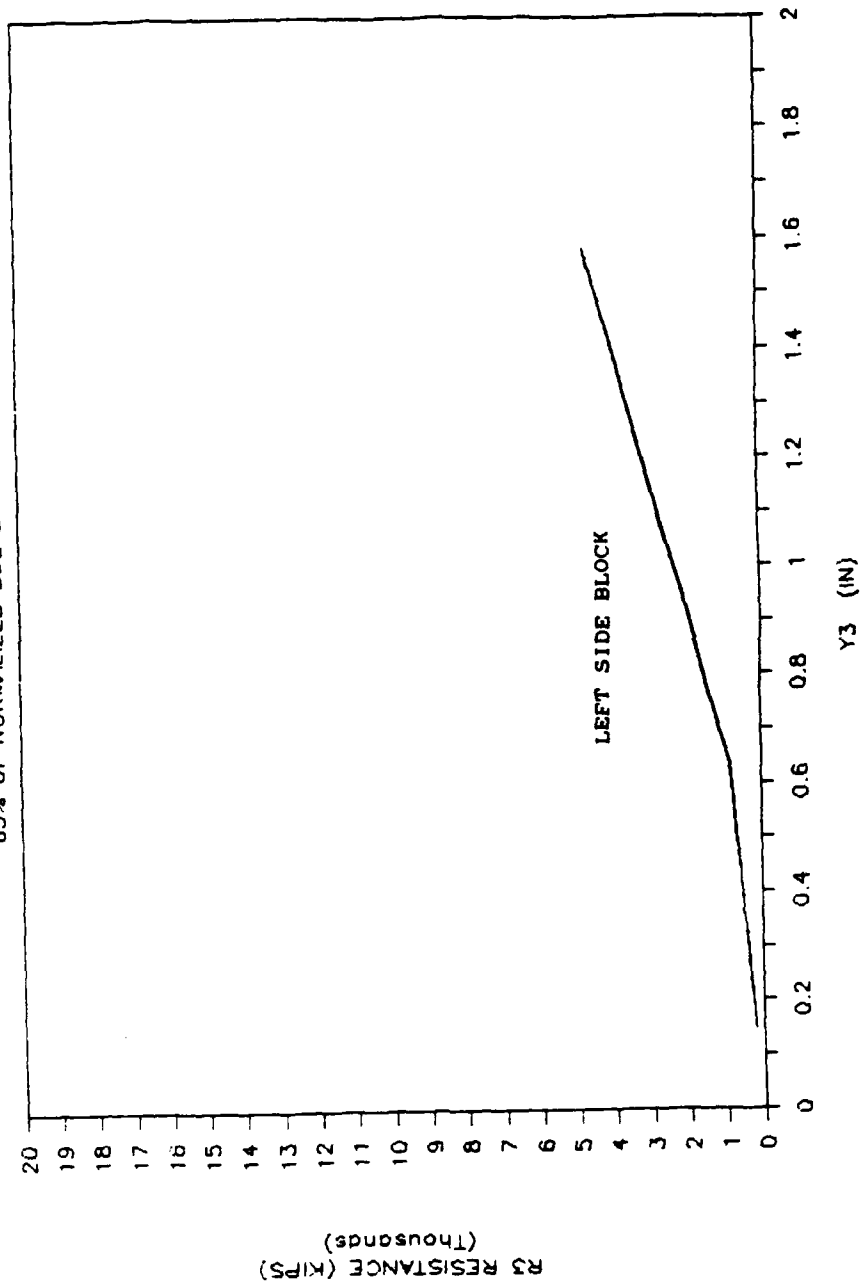


Low Stiffness Solution  
Right Side Block Vertical Displacement  
vs. Time  
63 % of Normalized DD2 Earthquake

Figure 7.15

Finally, figures (7.16 through 7.18) show the bilinear behavior of the rubber caps. The plots show that the keel blocking system starts out and remains on the second rubber bilinear stiffness slope. For the side blocks, the plots show that both sets of side blocks experienced both rubber bilinear stiffness slopes. One very interesting issue seen in figure (7.16) is that as the left side block system unloaded, the rubber bilinear behavior significantly delays and prevents side block liftoff from occurring. The smaller slope near zero load helps to keep the submarine in the side blocks. This is the primary reason rubber is a superior material for use as a blocking system cap.

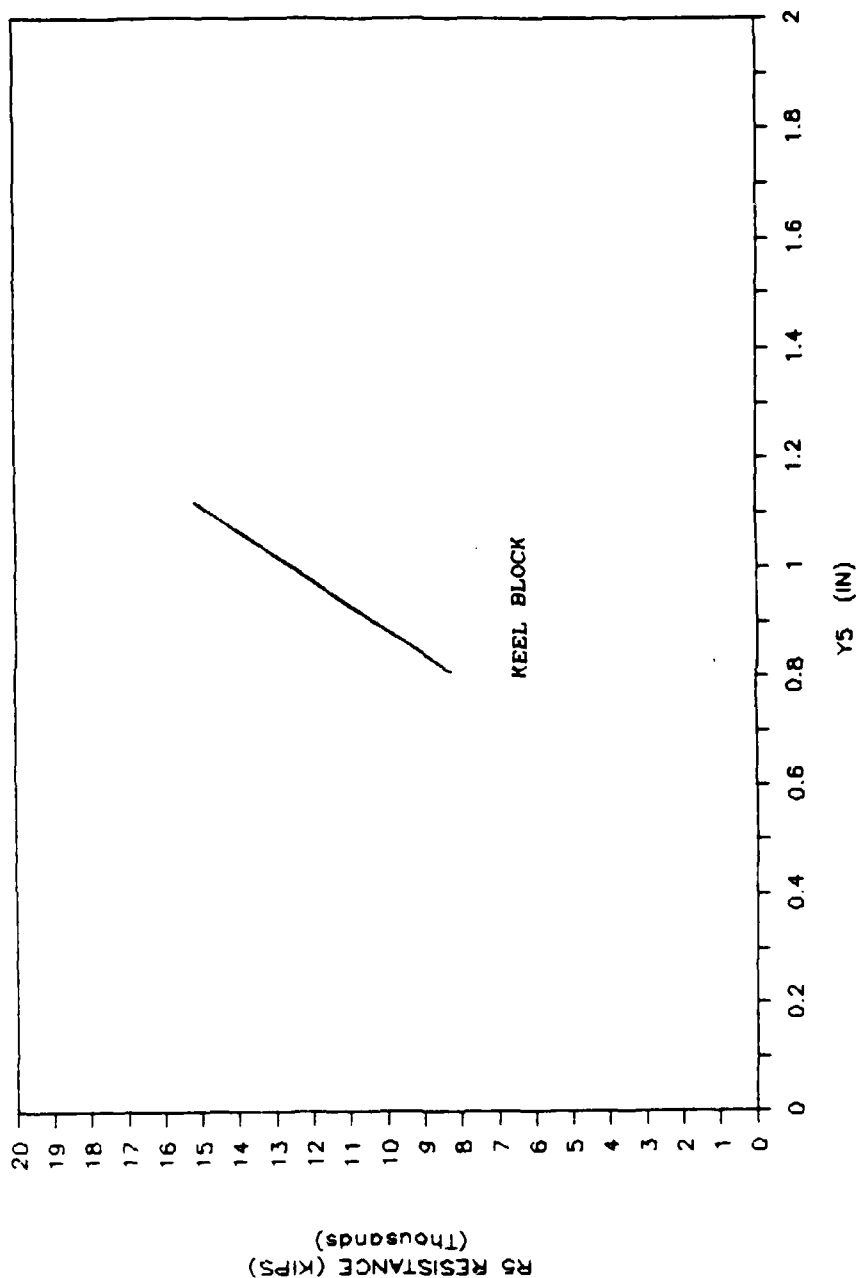
# SYSTEM #893 R3 VS Y3 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Right Side Block Vertical Force  
vs. Left Side Block Vertical Displacement  
63 % of Normalized DD2 Earthquake

Figure 7.16

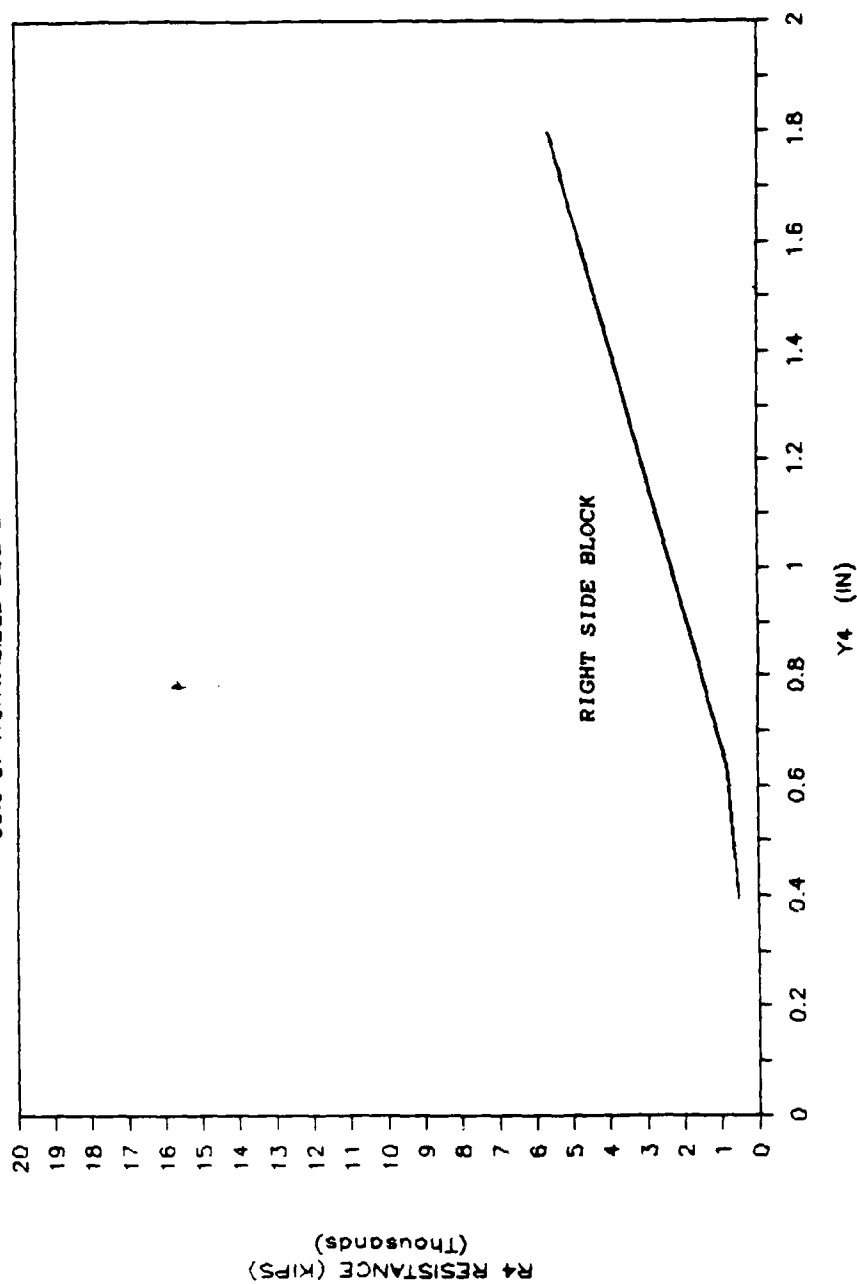
# SYSTEM #893 R5 VS Y5 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Keel Block Vertical Force  
vs. Keel Block Vertical Displacement  
63 % of Normalized DD2 Earthquake

Figure 7.17

# SYSTEM #893 R4 VS Y4 63% OF NORMALIZED DD2 EARTHQUAKE



Low Stiffness Solution  
Left Side Block Vertical Force  
vs. Right Side Block Vertical Displacement  
63 % of Normalized DD2 Earthquake

Figure 7.18

## CHAPTER 8

### WALE SHORE HIGH STIFFNESS DESIGN

#### 8.0 Design Process

As was shown in the section 5.1 wale shore parametric study, the use of wale shores is also a promising solution to the submarine drydock blocking system survivability problem. The use of wale shores increases system survivability by reducing the rotation and horizontal displacement of the submarine during the earthquake. Wale shores also shift the horizontal and rotational modal frequencies well above the fundamental frequencies of the earthquake.

From the wale shore parametric study, it is found that using wale shores with stiffnesses greater than or equal to 6000 kips/in along with one inch rubber keel and side block caps produce system survivability well in excess of dry dock failure. This is illustrated in figure (5.4). In order to compare the high stiffness solution with the low stiffness solution described in chapter 7, a system which survives 72 % of the 1940 El Centro earthquake is designed. The input data file and the output file from "3DOFRUB", which realize this level of survivability, is included in Appendix 6. Also included in this appendix is the output file for this system using the normalized dry dock # 2 earthquake excitation.

The 72 % (0.32 g's) survivability level is desirable to give the system a reasonable factor of safety above the 0.26 g dry dock failure level. For the low stiffness design only 63 % (0.28 g's) survivability could be attained due to excitation by the normalized dry dock # 2 earthquake before practical manufacturing limits of the isolator system are reached. This level of survivability is still considered acceptable.

The next step in this study is to determine how to practically realize this design. Once the required total stiffness of the wale shores is determined, the actual number and dimensions of the individual wale shores has to be found. The first assumption made is to design the wale shores for Long Beach Naval Shipyard dry dock # 2, which is a typical U.S. Naval shipyard graving dock. This requires the lengths of the wale shores to be approximately 32 feet when supporting a system 1 submarine.

Since the wale shores are compression elements vulnerable to buckling, based on Hughes [19] wide flange steel sections are chosen for the wale shores. In order to minimize dry dock production interference and to avoid overstressing the submarine, wale shores are only placed over existing side block pier locations. Therefore, the wale shores would bear on the submarine ring stiffeners. To determine the required individual wale stiffness, the number of wale shores is first assumed to be seven. Then a spreadsheet similar to that used



to calculate blocking pier vertical stiffness is used to determine what steel section is required to give the necessary overall wale shore stiffness. This spreadsheet is included in Appendix 6.

It is assumed that each wale shore would consist of a layer of rubber, a half inch steel backing plate, and a wide flange steel beam. To prevent separation of the wale shore from the submarine during the earthquake the wale shore is initially compressed against the submarine using an hydraulic jack. A satisfactory steel section is found using a steel wide flange beam design table in Popov [20].

Once a section is selected, it is tested for buckling survivability using the following procedure:

1. Using Hughes' column design curves [19], a value of ultimate stress for a single wale shore is obtained. The appropriate curve for a wide flange (universal column) is selected. This curve takes into account eccentricities in the beam.
2. To enter the curve a yield stress is required. 33000 psi mild steel is used.
3. Next, a slenderness ratio,  $L_e/r$ , is needed. This is obtained from Popov [20]. For simply supported conditions  $L_e$  is equal to the length of the beam.

The value of  $r$ , the radius of gyration, is found from Popov's beam design table.

4. The actual stress in the beam then has to be determined. This is accomplished by determining the force in the wale shore and dividing it by the sectional area of the beam,  $A_{wb}$ . The equations for the wale shore stress,  $\sigma_{wb}$ , are as follows:

$$\sigma_{wb} = R/A_{wb} \quad (8.1)$$

$$R = k_{sp}' \cdot x'_{max} + F_j \quad (8.2)$$

$$F_j = (D_j - XEL) \cdot k_{sp}' + A_{rub} \cdot \sigma_{rub} \quad (8.3)$$

$$XEL = (A_{rub} \cdot \sigma_{rub}) / k_{sp}' \quad (8.4)$$

$$D_j = x'_{max} \quad (8.5)$$

where:

$R$  = maximum total force seen by an individual wale shore.

It includes the maximum earthquake forces and the initial compressive forces applied by the hydraulic jack.

$k_{sp}'$  is the total stiffness of an individual wale shore when its rubber cap is operating on its second bilinear stiffness slope.

$x'_{max}$  is the maximum horizontal deflection seen by the wale shore as determined from the output of "3DOFRUB" using the height of the wale shore above the keel,  $AAA$ , the rotation angle  $\theta$ , and the keel horizontal displacement  $x$ .

$F_j$ , the jacking force, is the initial force applied to wale shore by the hydraulic jack to prevent separation.

$D_j$  is the initial deflection of wale shore caused by the jacking force.

$X_{EL}$  is the elastic limit deflection where the wale shore stiffness changes slope.

$A_{rub}$  is the cross sectional area of the rubber cap of the wale shore.

$\sigma_{rub}$  is the stress at which the rubber cap changes stiffness.

$k_s'$  is the total stiffness of an individual wale shore when its rubber cap is operating on its first bilinear stiffness slope.

5. The final check for buckling requires that  $\sigma_{wale}$  is less than  $\sigma_{crit}$ . In order to meet this requirement and maintain a reasonable wale shore size the number of wale shores has to be increased to 14. Table 8.1 lists the parameters obtained for the final high stiffness wale shore design which satisfies the buckling criteria.

Table 8.1

FINAL HIGH STIFFNESS DESIGN WALE SHORE  
PARAMETERS

# wale shores:	14 per side
Section:	27x14 WF 145 mild steel
$r$ :	3.09 inches
Length ( $L_e$ ):	385 inches
$L_e/r$ :	123.3
$k_s'$ :	134.15 kips/in
$k_{sp}'$ :	437.51 kips/in
XEL:	0.36 inches
$\sigma_{wa}$ :	9095 psi
$\sigma_{wa}$ :	13500 psi
$F_s$ :	138.79 kips
$D_s$ :	0.57 inches

It is assumed that during the earthquake the wale shore stiffness remains equal to  $k_{sp}'$ . The wale shore is designed so that there is a large enough rubber cap and enough initial compression supplied by the jack so that the wale shore never loses contact with the submarine during maximum horizontal displacement and rotation during the earthquake.

### 8.1 Description of the High Stiffness Solution

Figure (8.1) is a 2D drawing of the recommended high stiffness submarine dry dock blocking system solution. This solution survives 72 % (0.32 g's) of the 1940 El Centro earthquake and 75 % (0.34 g's) of the normalized dry dock # 2 earthquake. The design includes the following features:

1. 14 wale shores are placed directly over the side block positions at a position half the diameter of the submarine up from the keel. They are attached to the dockside by a hinge-pin-jack assembly as shown in figure (8.2). Cables are used to support and align the the wale shores.
2. Each wale shore is 32 feet long. Table 8.1 describes the steel section used. A three inch rubber cap is placed between a backing plate and the submarine hull. A 70 ton jack is used to pre-compress the wale shore against the submarine to prevent separation during the earthquake.
3. The keel and side concrete blocking piers are rigidly attached to the dry dock floor to prevent overturning.
4. A steel carriage is rigidly attached to the caps and concrete blocking piers to prevent sliding. It also ties the system together longitudinally.
5. A one inch rubber cap is used on top of the steel carriage to help prevent liftoff.

# WALE SHORE HIGH STIFFNESS SOLUTION

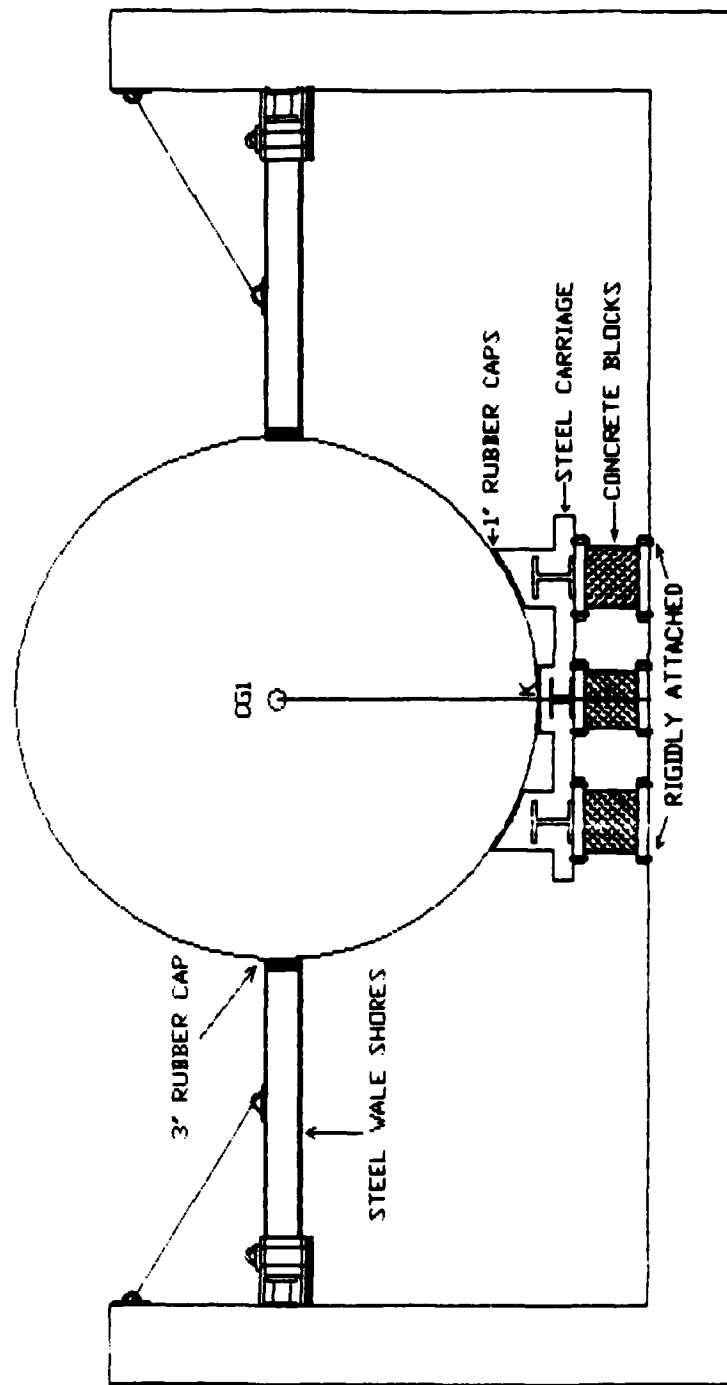


FIGURE 8.1

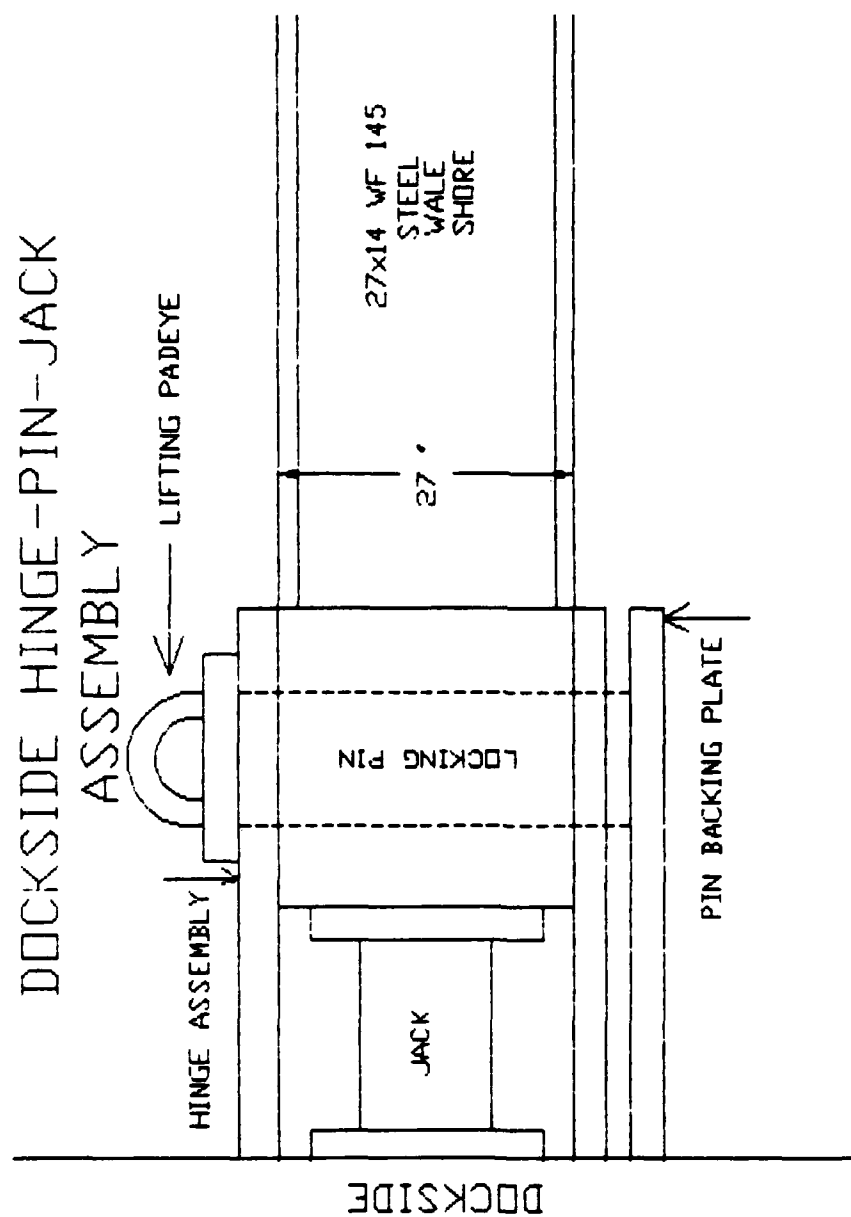


FIGURE 8.2

The "3DOFRUB" program could not completely model this system directly. Therefore, a few changes to the data file are required to simulate this system. First, the keel and side block widths are made extremely wide to simulate rigid attachment. In addition, the block on block friction coefficient is made extremely high to simulate the caps' rigid attachment to the steel carriage. The stiffness of the wale shores is assumed to remain on the second stiffness slope.

## 8.2 Response of the High Stiffness Solution

The response plots analyzed in this section for the high stiffness solution are due to excitation by 72 % of the 1940 El Centro earthquake. The natural frequencies of the high stiffness solution are so high that both the 1940 El Centro and the normalized dry dock # 2 earthquake produce similar levels of survivability (72% and 75%). This is an indication that the procedure used in section 6.1 to normalize the dry dock # 2 earthquake with the 1940 El Centro earthquake was done correctly. The 1940 El Centro earthquake is used to produce the output plots because it has higher frequencies and produces a lower level survivability; therefore, it is the more conservative earthquake to use in analyzing the high stiffness design.

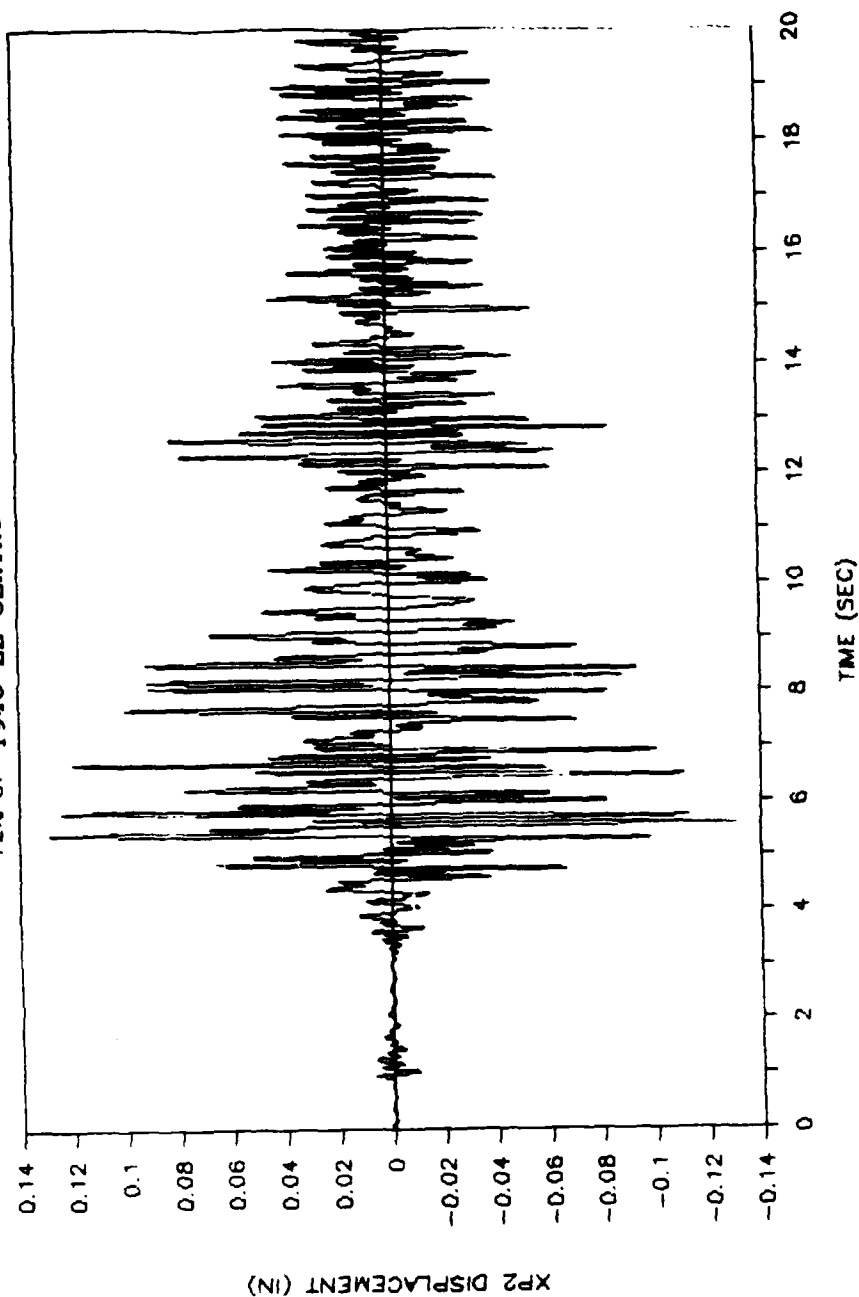
Figure (8.3) is a plot of the keel horizontal displacement relative to the dry dock floor as a function of



time. This plot shows that the high stiffness solution has relatively small horizontal displacements associated with it. However, the displacements are high in frequency and have abrupt transitions which means the submarine is experiencing high velocities and accelerations. This output is closely coupled to the horizontal earthquake excitation shown in figure (6.6).

These high accelerations can be seen in the keel block horizontal force versus time plot in figure (8.4). The high stiffness solution has keel block horizontal forces which are larger than the low stiffness forces described in chapter 7 by an order of magnitude. Figure (8.5) shows the rotational response of this system. This figure is a plot of the systems rotation about the keel versus time. This plot shows that the rotations are relatively small as is expected with use of wale shores. Figure (8.6) shows that the vertical displacement is coupled with the earthquake's vertical acceleration as is the case for low stiffness solution. Figure (8.7) is a plot of the left wale shore deflection versus time. In this figure, a positive deflection is compression and a negative deflection is expansion. The maximum amount of expansion the wale shores are designed to withstand is 0.57 inches.

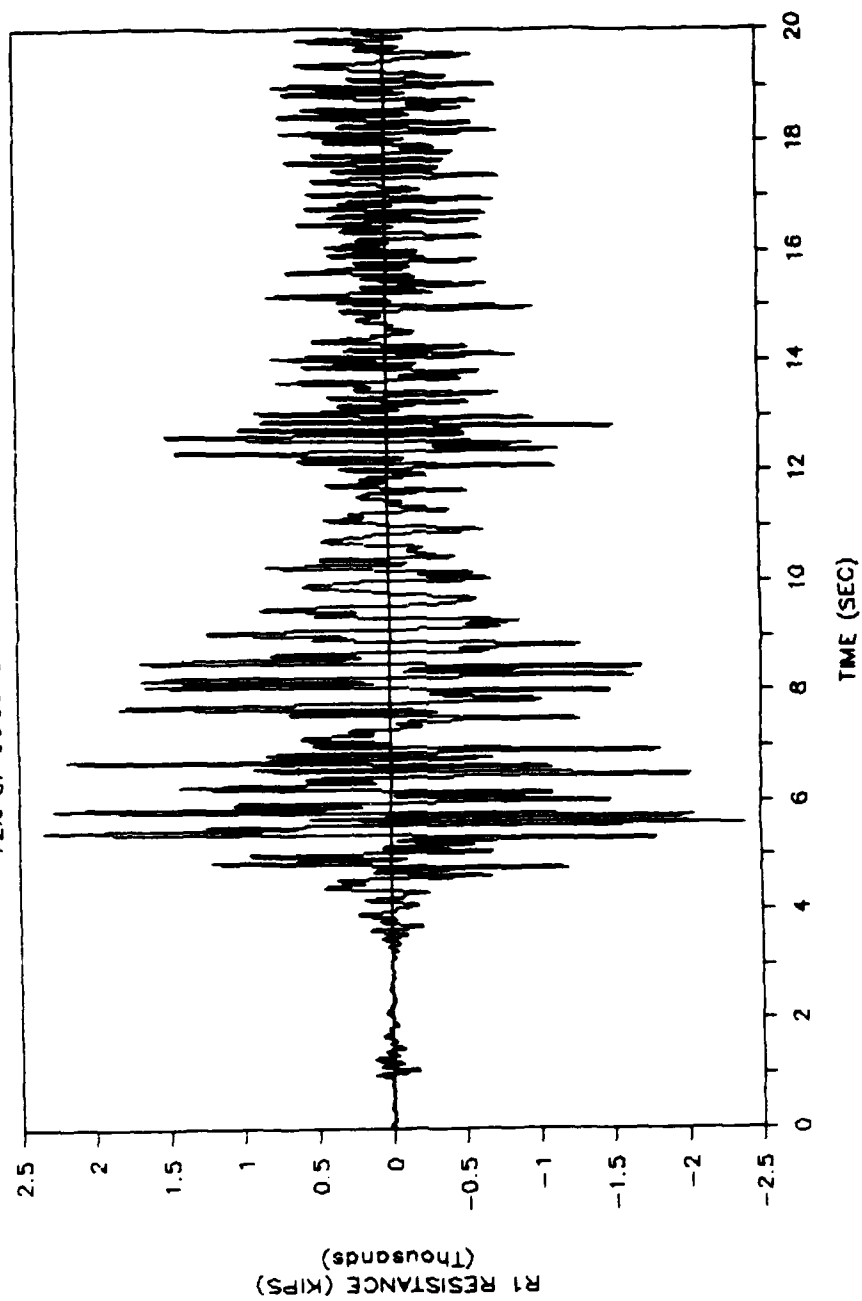
# SYSTEM #51 X1 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Keel Block Horizontal Displacement  
vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.3

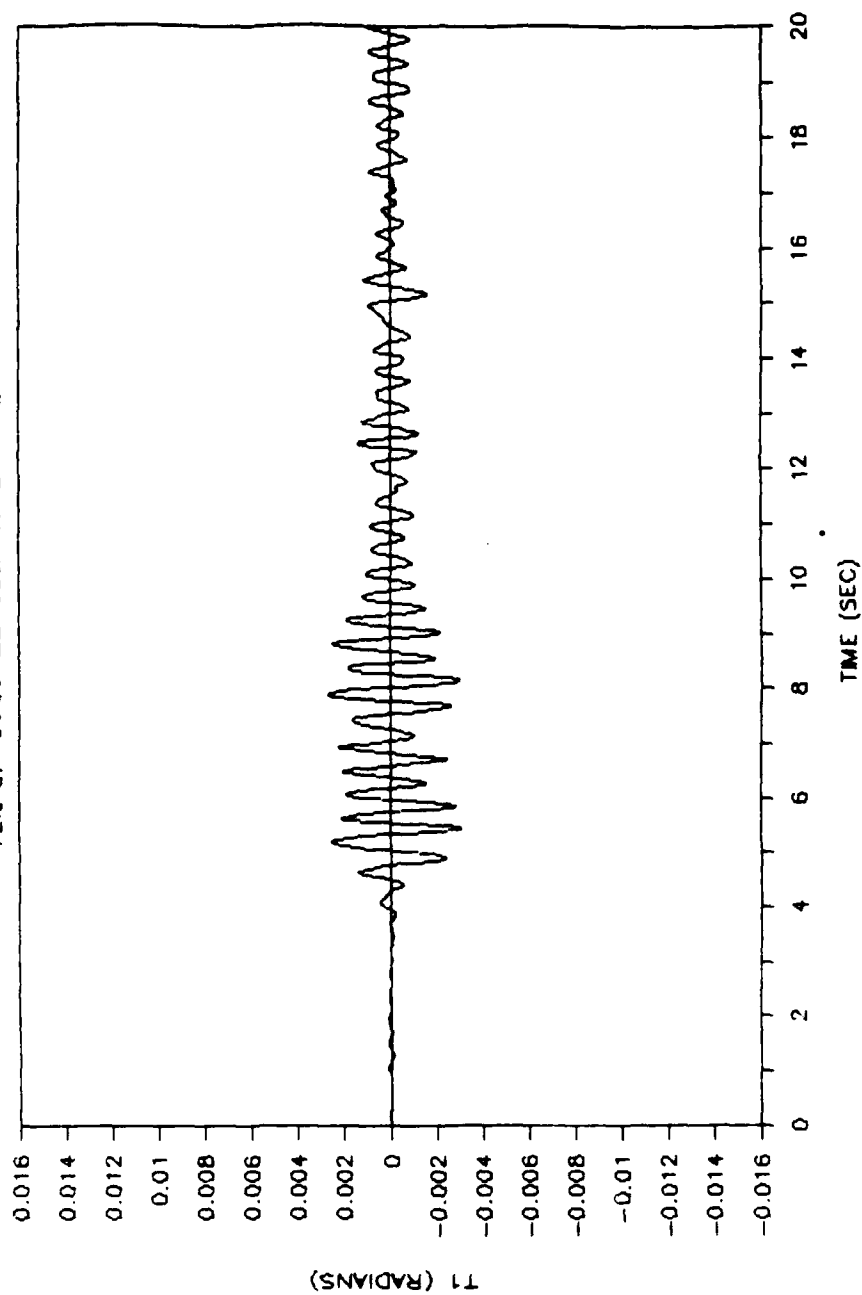
SYSTEM #51 R1 VS TIME  
72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Keel Block Horizontal Force  
vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.4

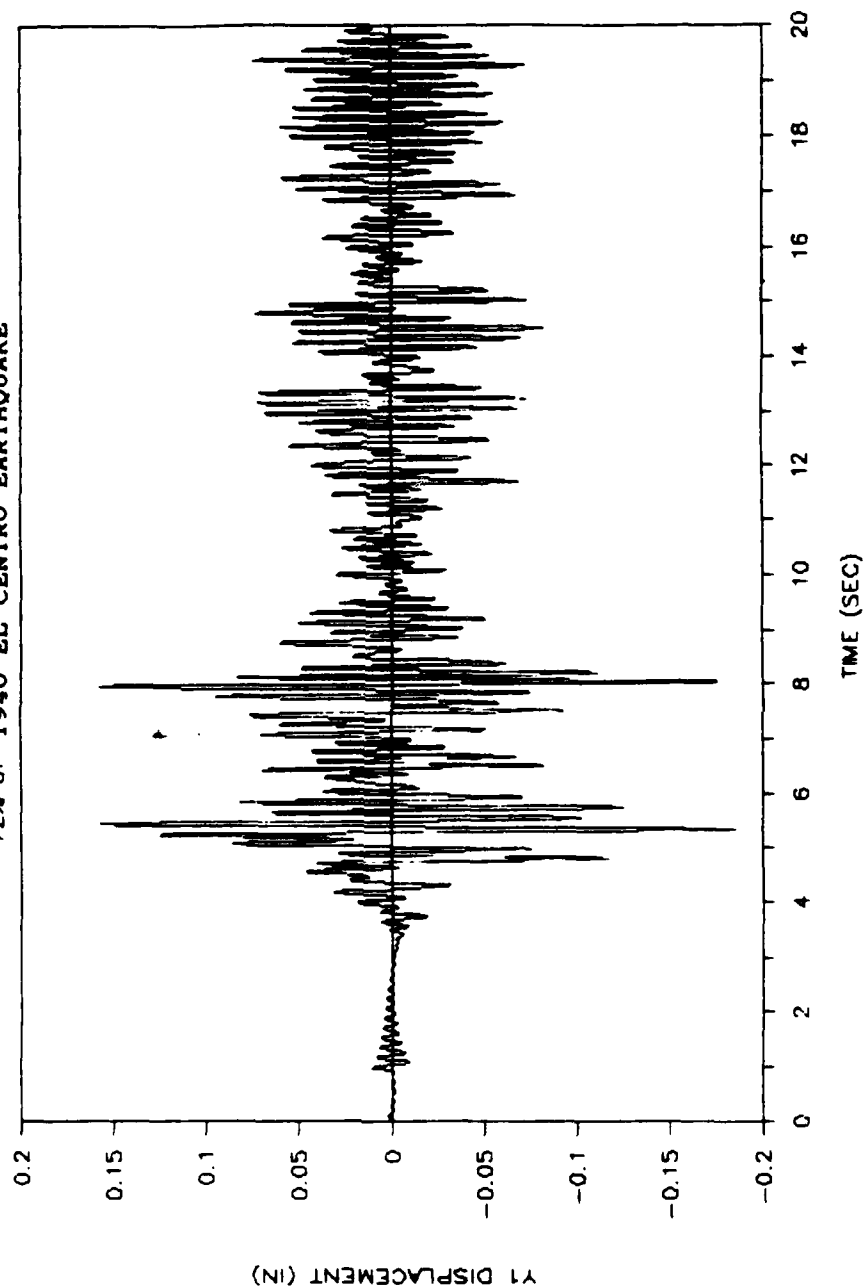
# SYSTEM # 51 T1 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution Rotation vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.5

# SYSTEM #51 Y1 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE

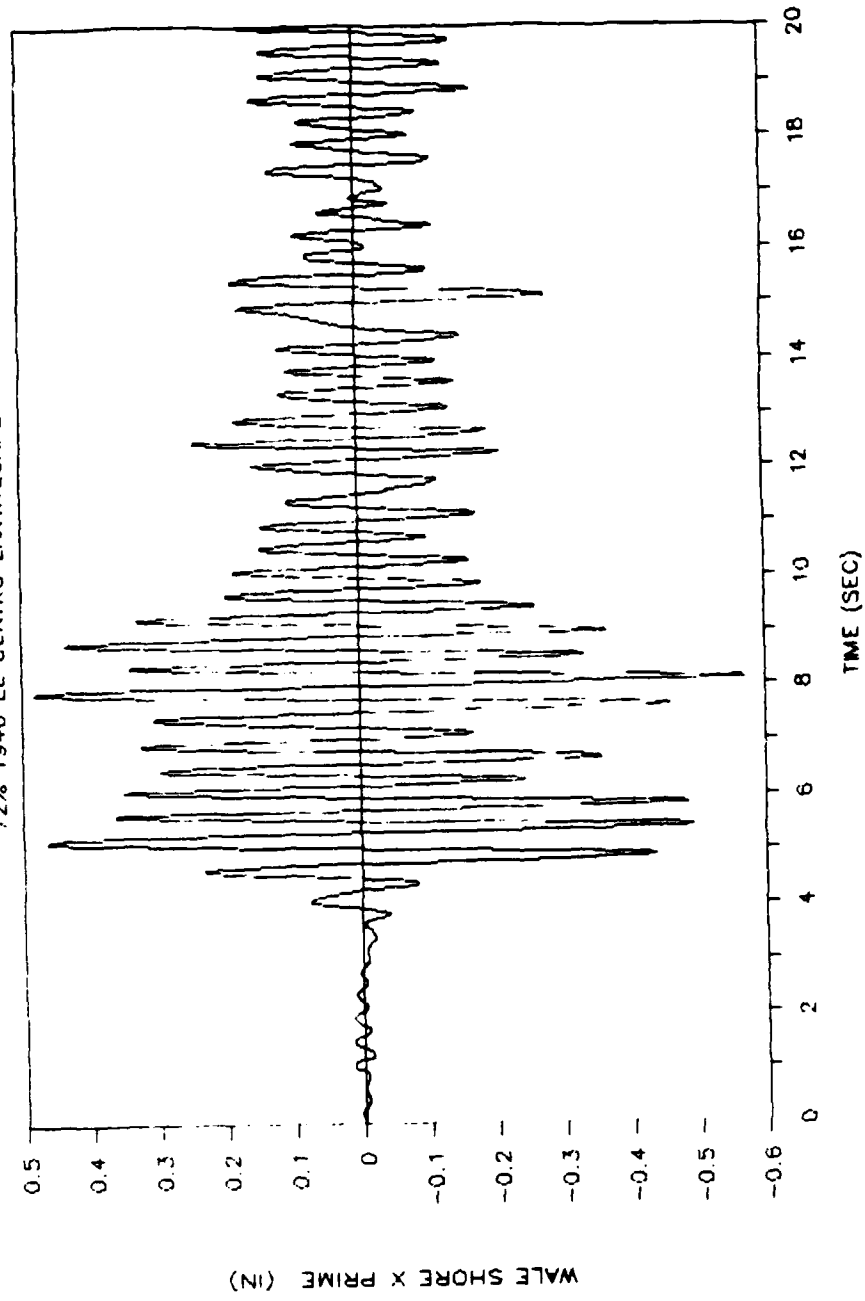


High Stiffness Solution  
Keel Block Vertical Displacement vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.6

# SYSTEM #51 WS XPRIME VS TIME

72% 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Wale Shore Horiz. Displacement vs. Time  
72 % of 1940 El Centro Earthquake

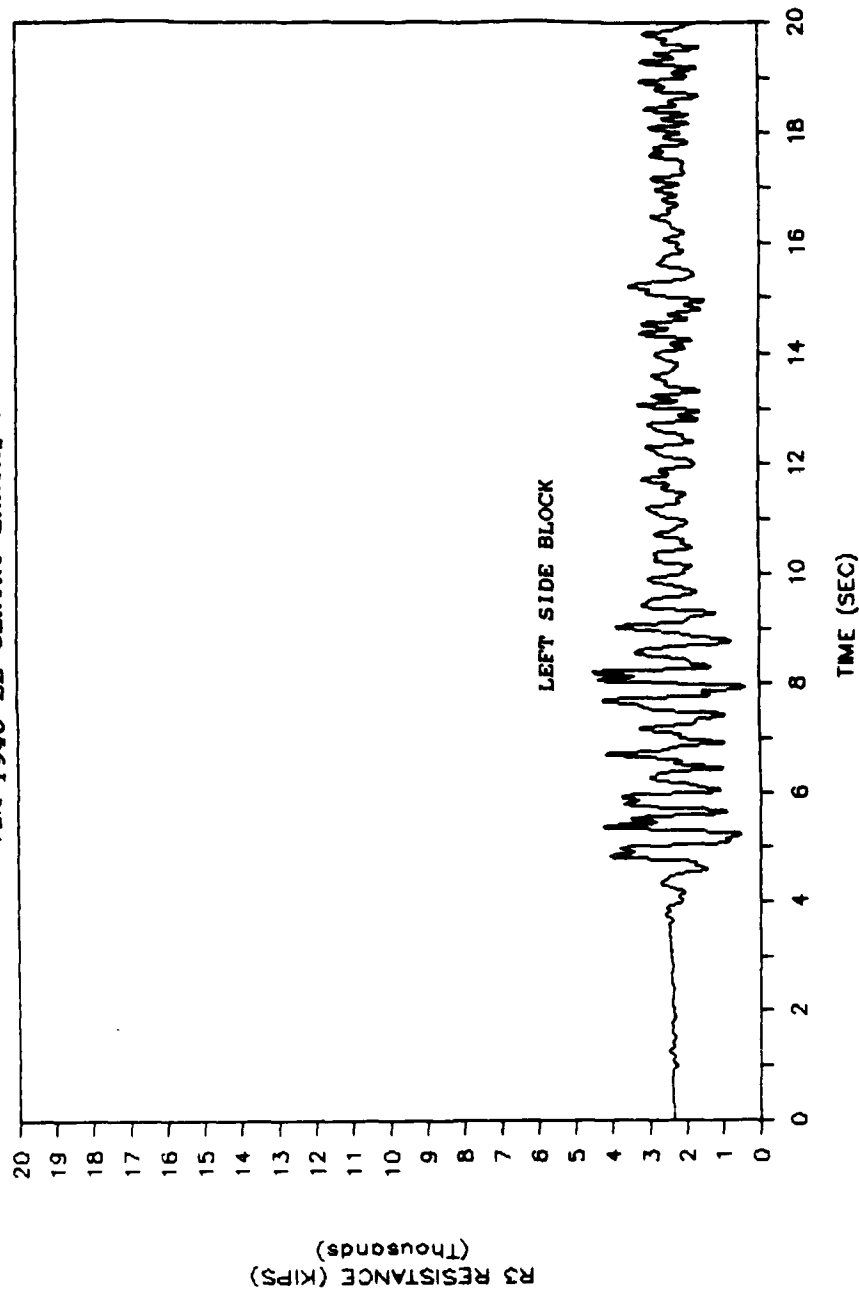
Figure 8.7

As seen in figure (8.7), the wale shores do not deflect beyond the maximum expansion limit. Therefore, no separation of the wale shores from the submarine occurs during this earthquake. Without precompression by the jacks, the wale shore would have separated from the submarine.

The forces on the left side blocks, keel blocks, and right side blocks are shown in figures (8.8 through 8.10) respectively. In these three figures, at time zero the total force on all three blocking systems is the weight of the submarine. The keel block system's load is 12000 kips (70 %), and each side block system's load is 2300 kips (15 %).

The side block force is mostly due to rotation of the submarine as can be seen by its similarity to figure (8.5) which is the plot of system rotation. The right and left side block plots are 180 degrees out of phase. The forces on the keel are due to a combination of static load and vertical displacement. As is the case with vertical displacement, the keel vertical forces are coupled with the vertical earthquake excitation.

# SYSTEM #51 R3 VS TIME 72% 1940 EL CENTRO EARTHQUAKE

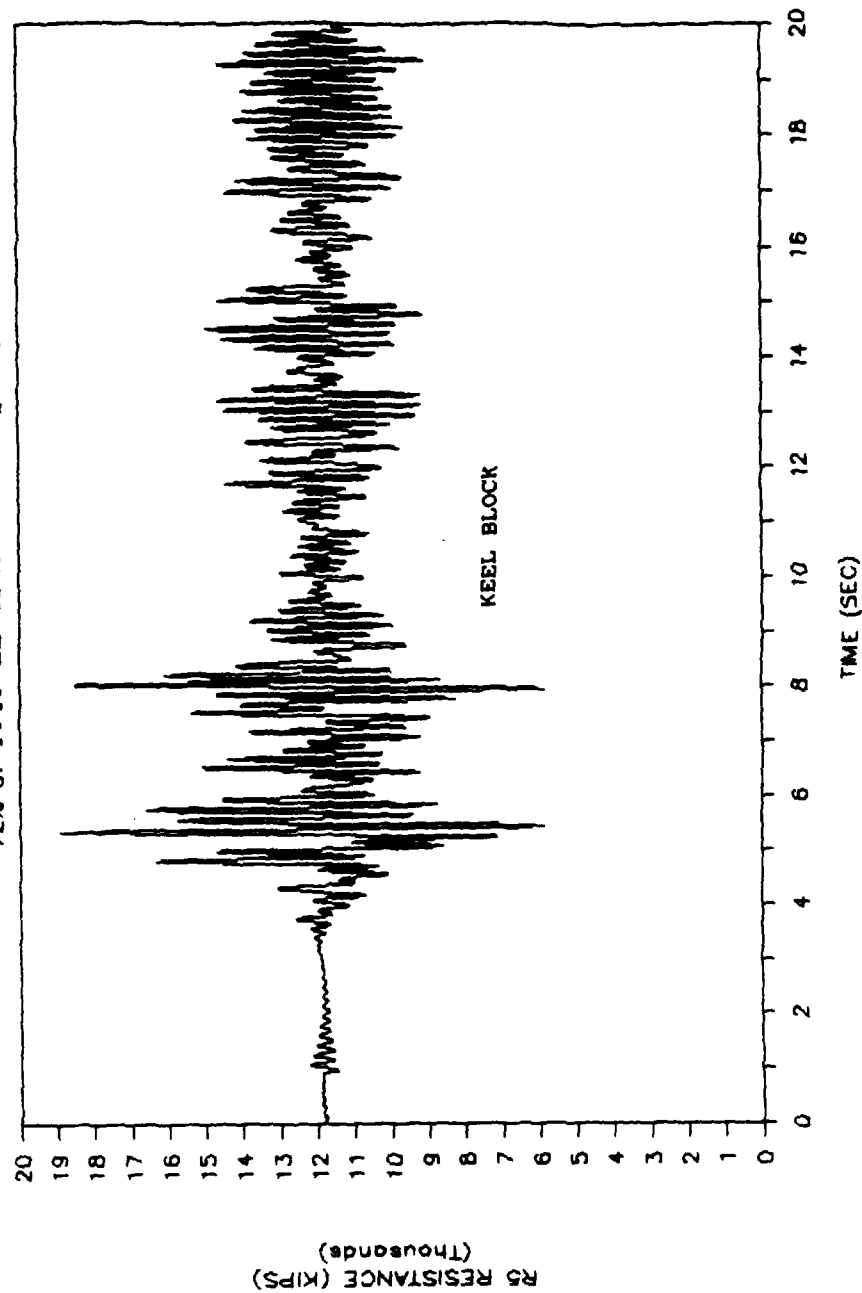


High Stiffness Solution  
Right Side Block Vertical Force vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.8



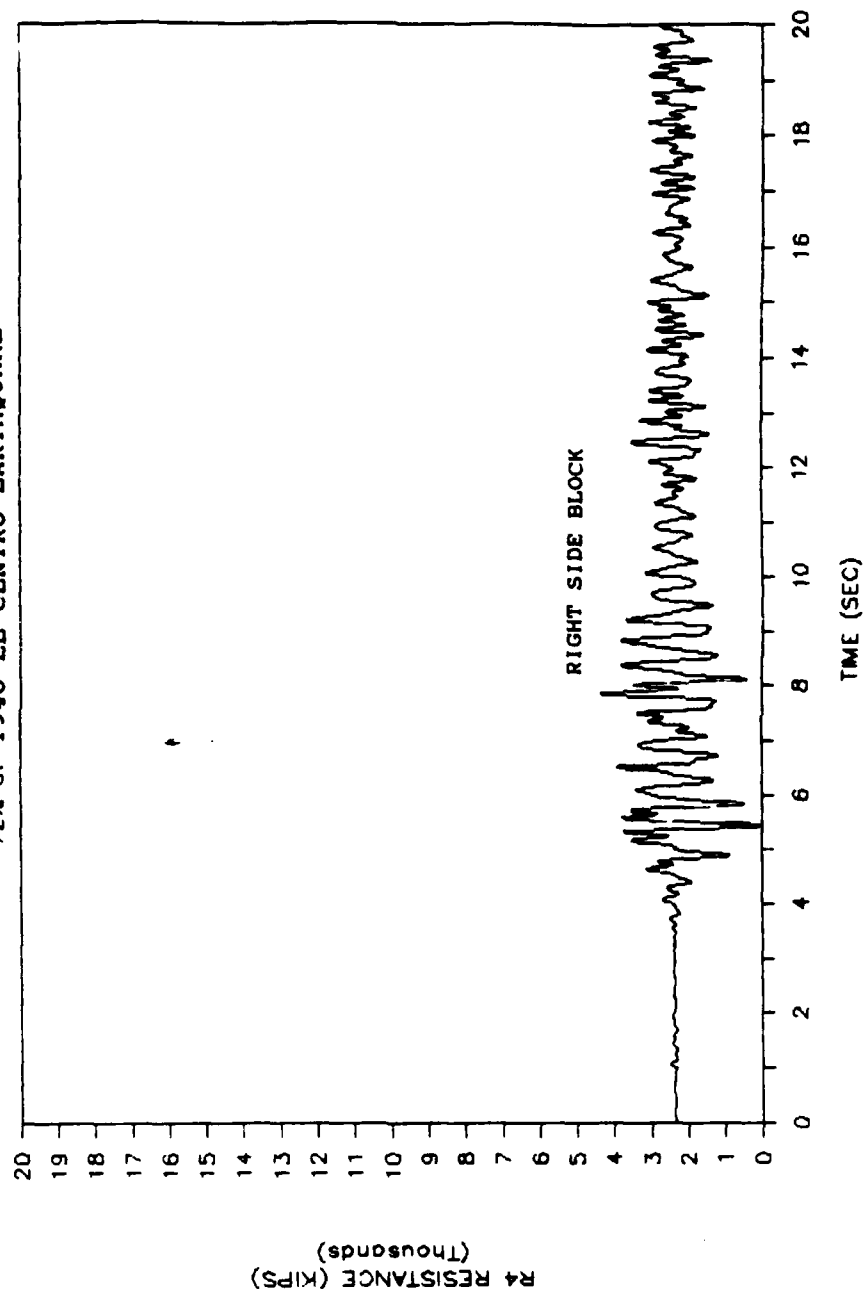
# SYSTEM #51 R5 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Keel Block Vertical Force vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.9

# SYSTEM #51 R4 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



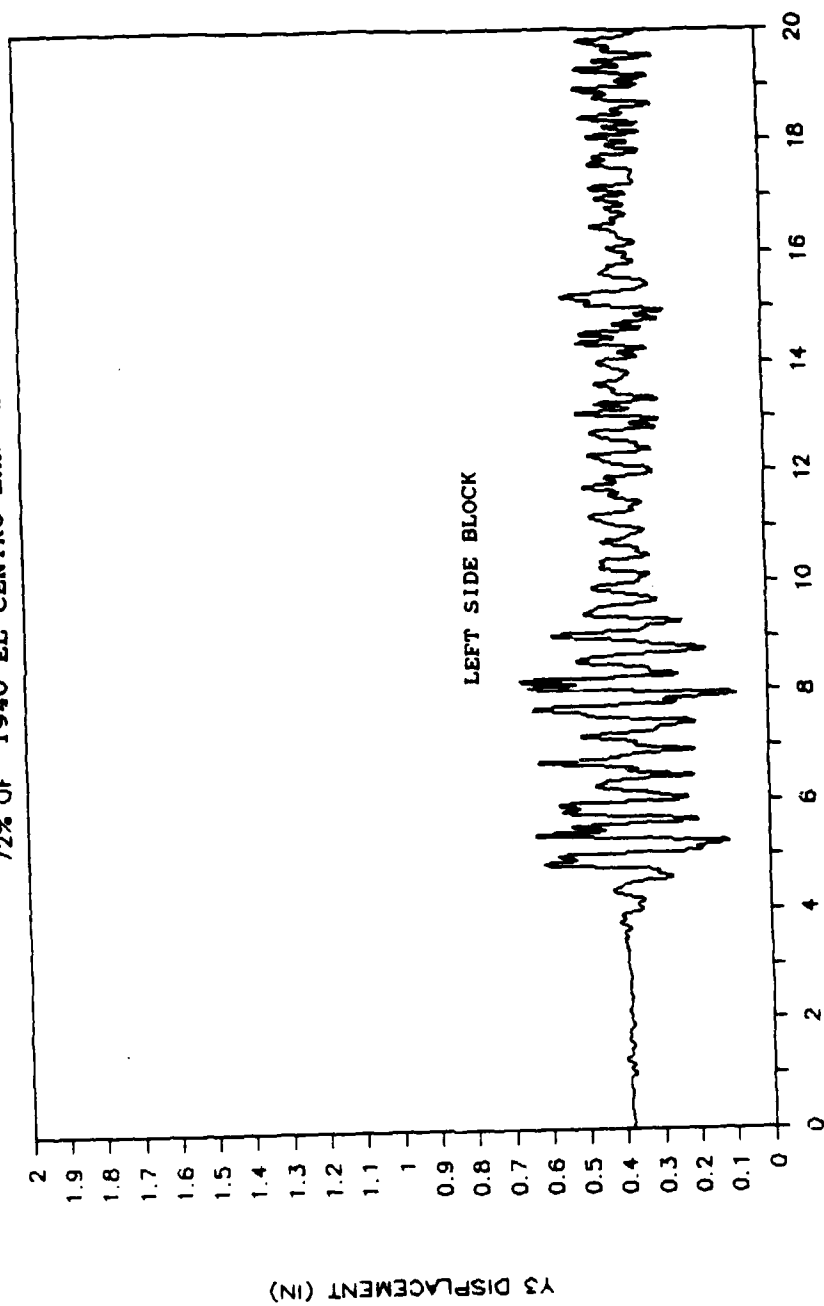
High Stiffness Solution  
Left Side Block Vertical Force vs. Time  
72 % of 1940 El Centro Earthquake . . . .

Figure 8.10

The displacements of the left side blocks, keel blocks, and right side blocks are shown in figures (8.11 through 8.13) respectively. At time zero, the plots represent the static deflection caused by the submarine's weight. All three systems initially have the same displacement. The initial displacement is approximately 0.38 inches into the rubber cap. This static displacement is only about one-third of that for the low stiffness solution which has 6 inch rubber caps instead of 1 inch. The plots show that liftoff does not occur; however, for the left side block system liftoff came within 0.01 inches of occurring. The right side block system also came within 0.01 inches of liftoff. Even though the high stiffness solution is closer to side block liftoff than the low stiffness solution, since the range of displacement of side blocks is much less for the high stiffness solution the susceptibility of liftoff for both solutions is approximately the same.

Finally, figures (8.14 through 8.16) show the bilinear behavior of the rubber caps. The plots show that the keel blocking system starts out and remains on the second rubber bilinear stiffness slope. For the side blocks, the plots show that both sets of side blocks experience both rubber bilinear stiffness slopes. Figure (8.16) shows how close the right side block is to lifting off. This is reasonable considering failure occurs at a one percent higher earthquake magnitude due to side block liftoff.

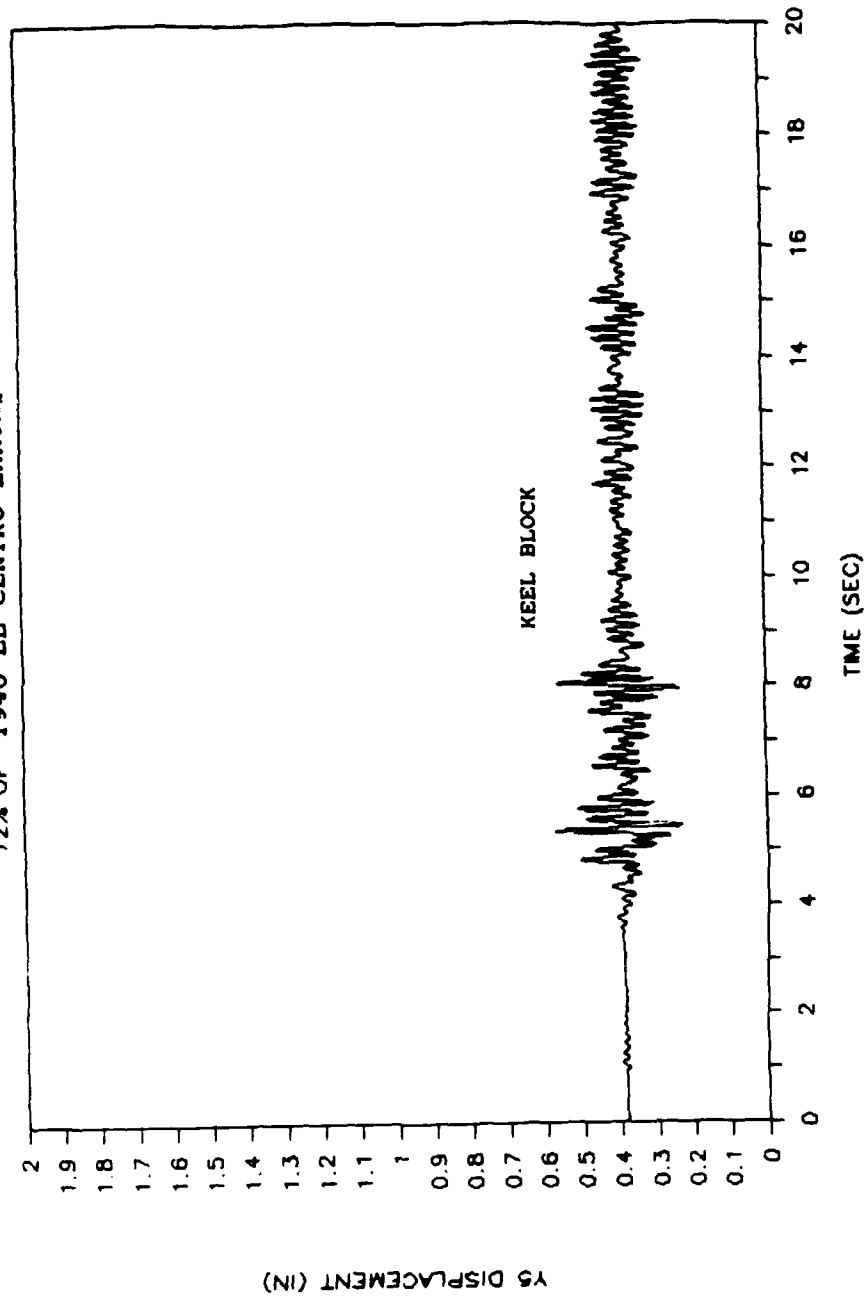
# SYSTEM #51 Y3 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Left Side Block Vertical Displacement  
vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.11

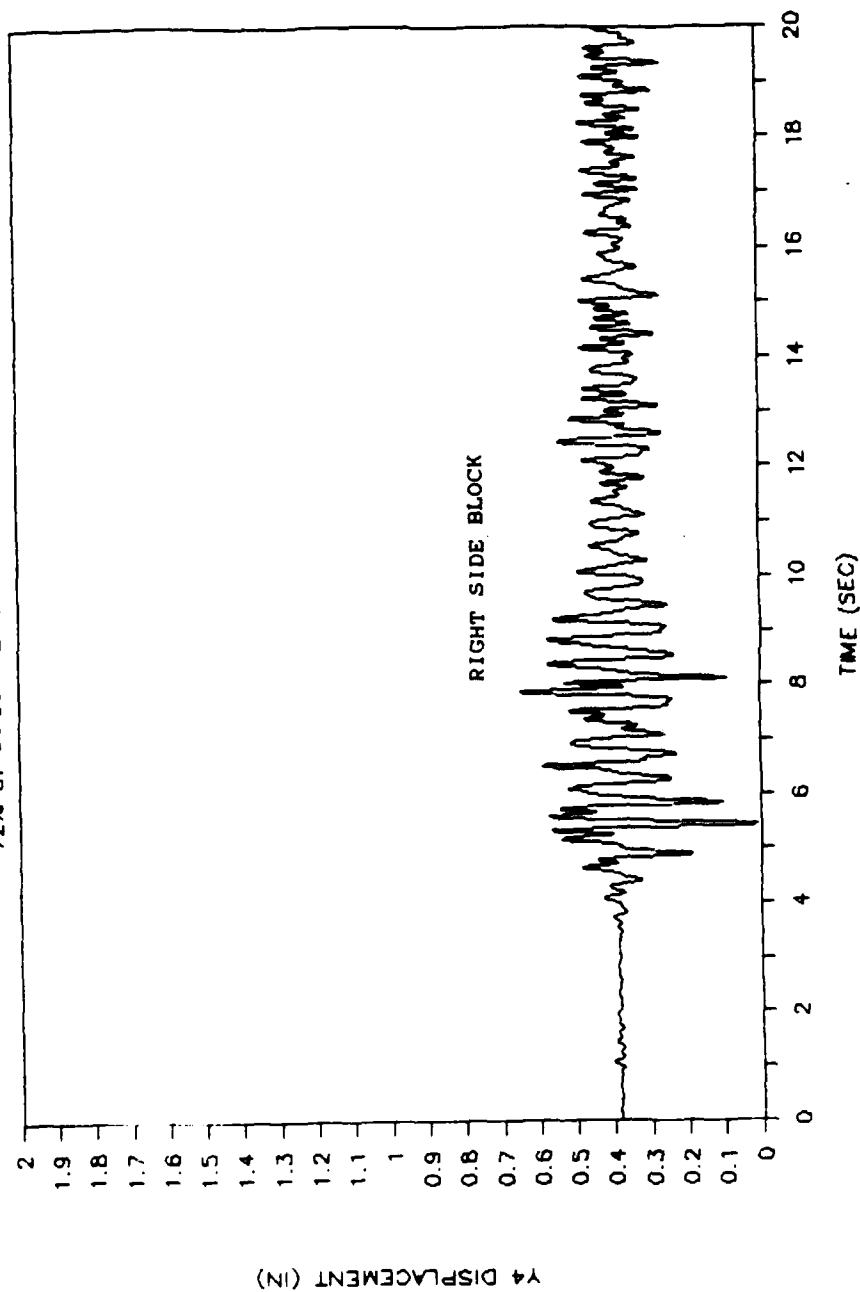
# SYSTEM #51 Y5 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Keel Block Vertical Displacement vs. Time  
72 % of 1940 El Centro Earthquake

Figure 8.12

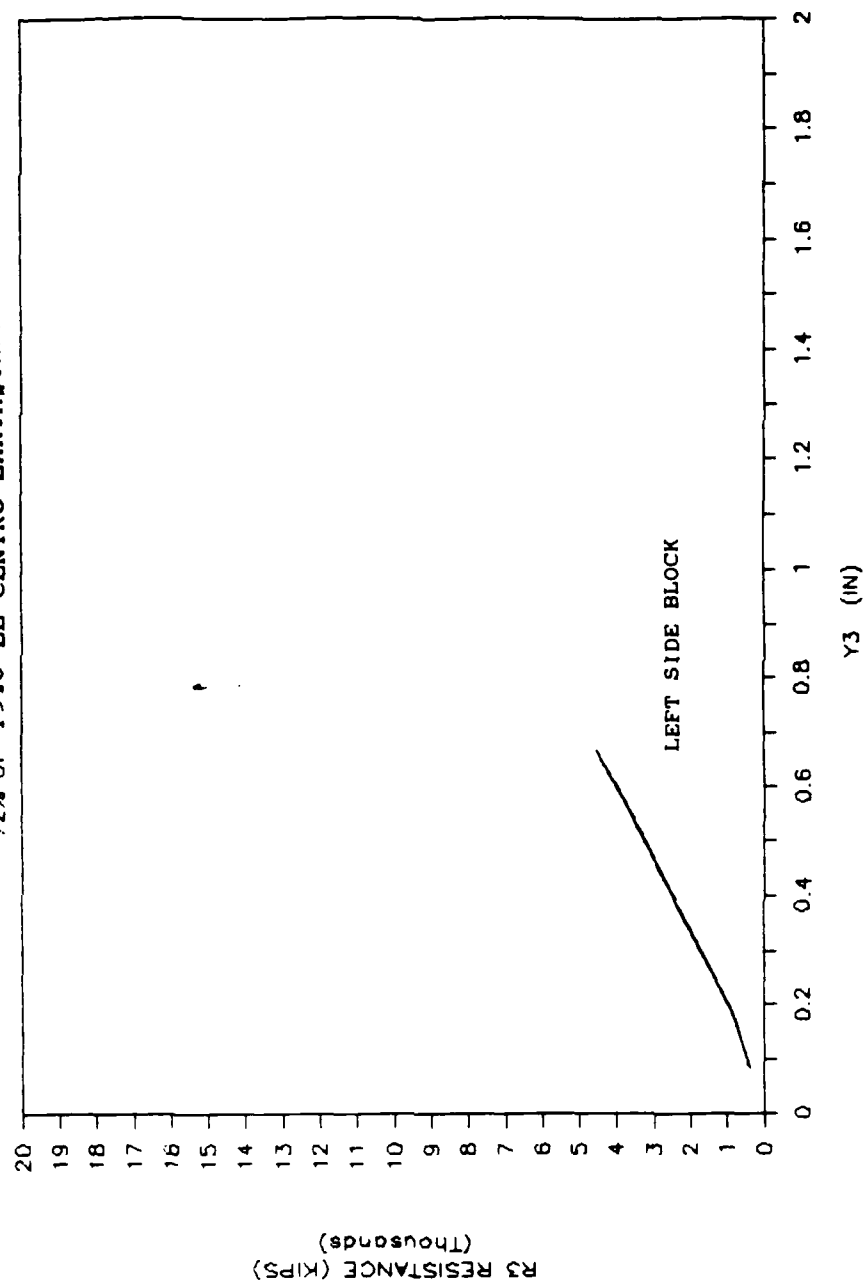
# SYSTEM #51 Y4 VS TIME 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Right Side Block Vertical Displacement  
vs. Time  
72 % of 1940 El Centrio Earthquake

Figure 8.13

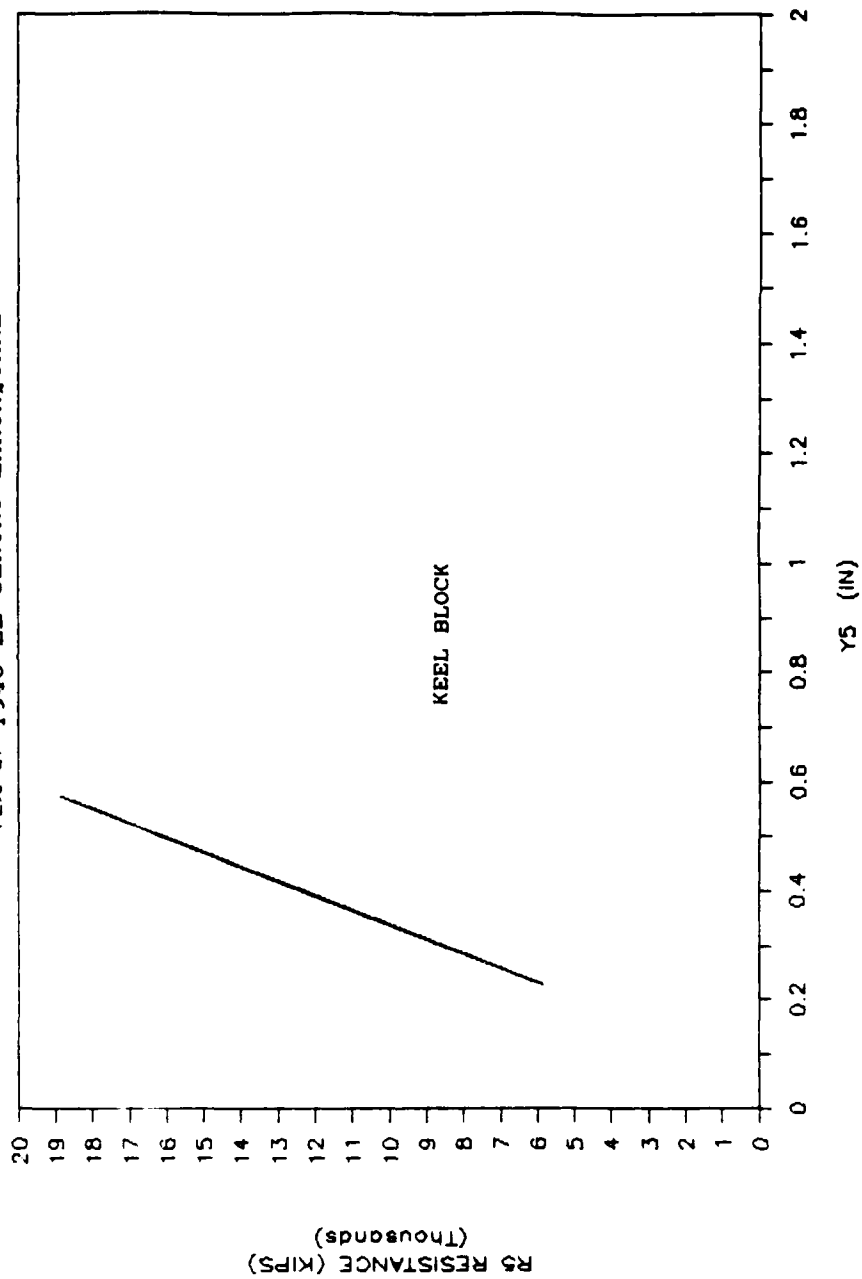
# SYSTEM #51 R3 VS Y3 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Right Side Block Vertical Force  
vs. Left Side Block Vertical Displacement  
72 % of 1940 El Centro Earthquake

Figure 8.14

# SYSTEM #51 R5 VS Y5 72% OF 1940 EL CENTRO EARTHQUAKE

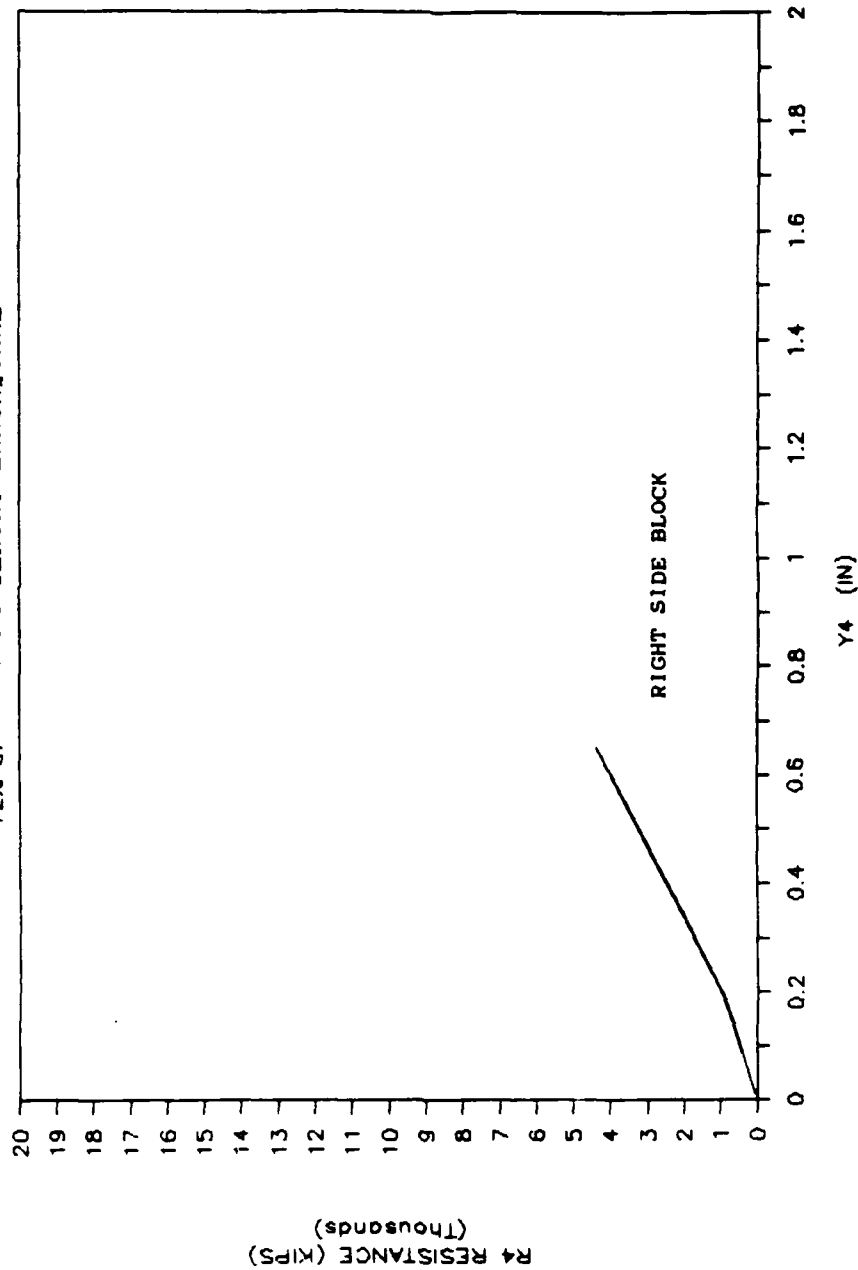


High Stiffness Solution  
Keel Block Vertical Force  
vs. Keel Block Vertical Displacement  
72 % of 1940 El Centro Earthquake

Figure 8.15



# SYSTEM #51 R4 VS Y4 72% OF 1940 EL CENTRO EARTHQUAKE



High Stiffness Solution  
Left Side Block Vertical Force  
vs. Right Side Block Vertical Displacement  
72 % of 1940 El Centro Earthquake

Figure 8.16

## CHAPTER 9

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

#### 9.0 Summary of Results

This thesis described the development of the three degree of freedom submarine drydock blocking system design package based on the "3DOFRUB" computer program. The differential equations of motion are developed to include the effect of high blocking systems and wale shores. The sliding failure mode is modified to more accurately take into account the effects of cap angle.

A case study is undertaken involving the earthquake sliding failure of the *USS Leahy* (CG-16) while in a graving dock at Long Beach Naval Shipyard. This study verifies the accuracy and usefulness of the "3DOFRUB" program. A parametric study is conducted to determine the effects of wale shores, isolators, and block stiffness and geometry variations on system survivability. The effects of using earthquake acceleration time histories with differing frequency spectrums on system survivability is studied.

Eleven submarine drydock blocking systems are studied using linear wood caps, bilinear wood caps for two different earthquakes, and one inch bilinear rubber caps. None of these systems survive to dry dock failure (0.26 g's) or even met the

U.S. Navy earthquake acceleration survivability criteria (0.20 g's). This shows that current U.S. Navy submarine drydock blocking systems are inadequate to survive expected earthquakes. Figure (9.1) illustrates the survivability levels of the various systems studied.

Two design solutions are found that met the dry dock failure requirements. The low stiffness solution uses dynamic isolators and rubber caps, and the high stiffness solution uses wale shores and rubber caps. The survivability of these two solutions when excited by the 1940 El Centro Earthquake is plotted in figure (9.2). This figure also includes the survivability of submarine system 1 using linear and bilinear wood, one inch rubber caps, and dynamic isolators. Both of the solutions have the same survivability level, and provide a reasonable margin of safety over the dry dock failure level.

# SURVIVAL % COMPARISONS SIGMAN BILINEAR LINEAR RUBBER DD2

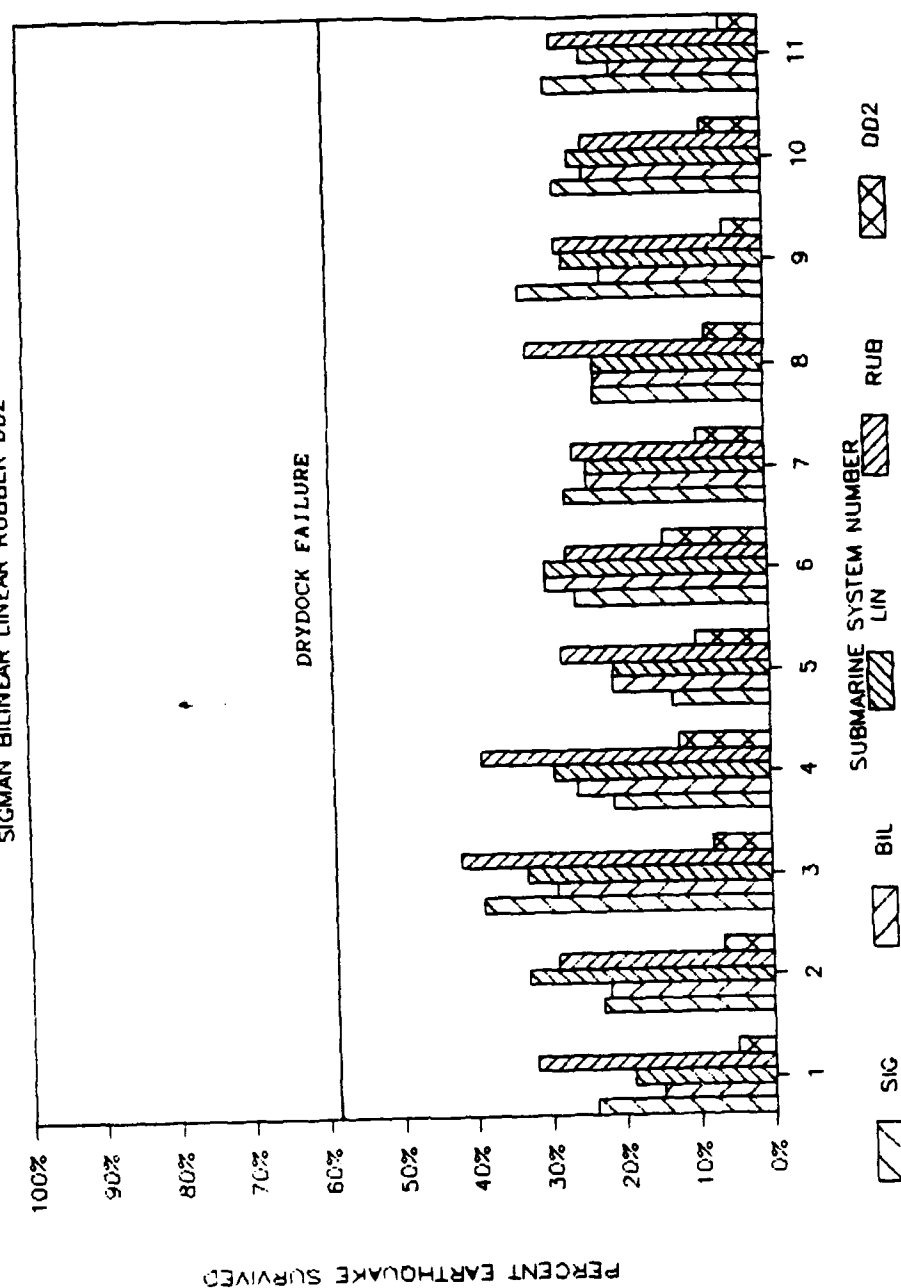


FIGURE 9.1

# SUBMARINE DRYDOCK BLOCKING SYSTEM # 1

SURVIVABILITY COMPARISON

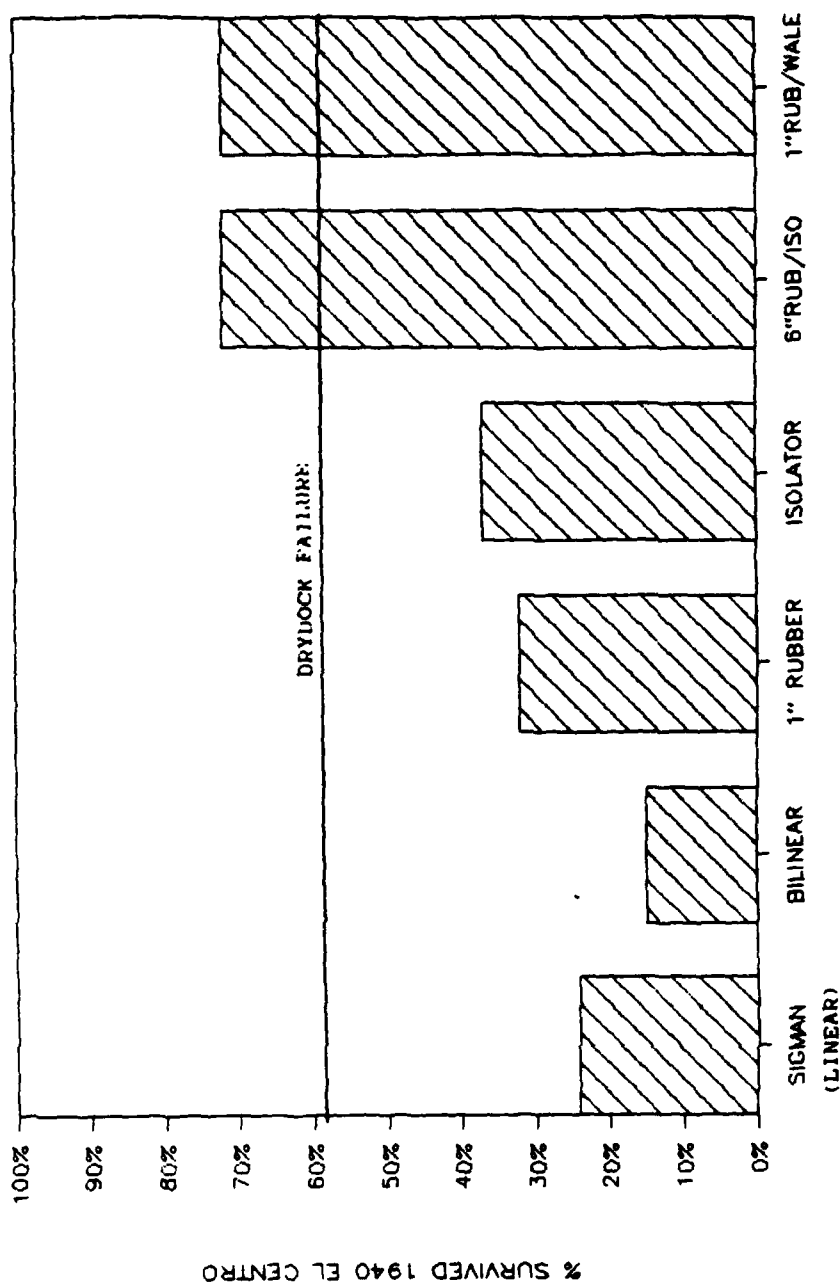


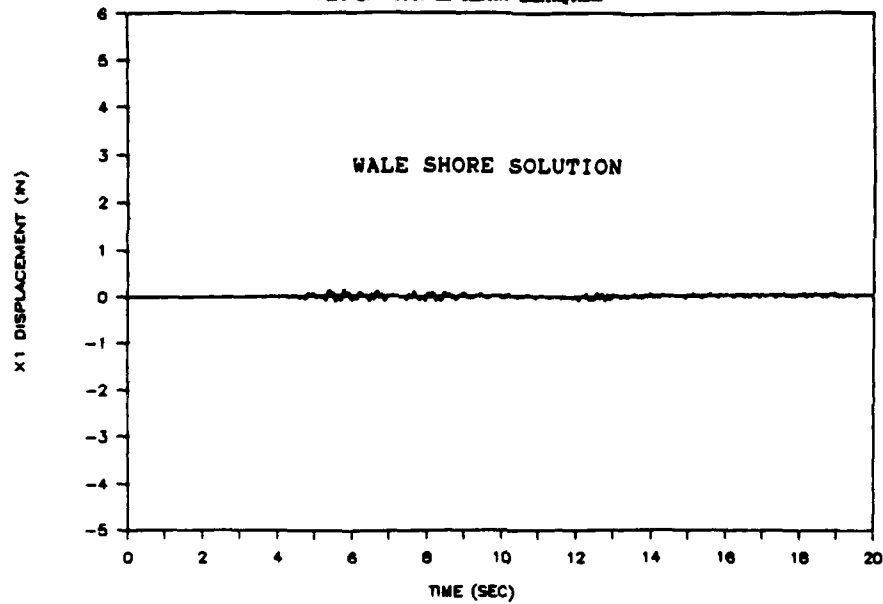
FIGURE 9.2

## 9.1 Conclusions

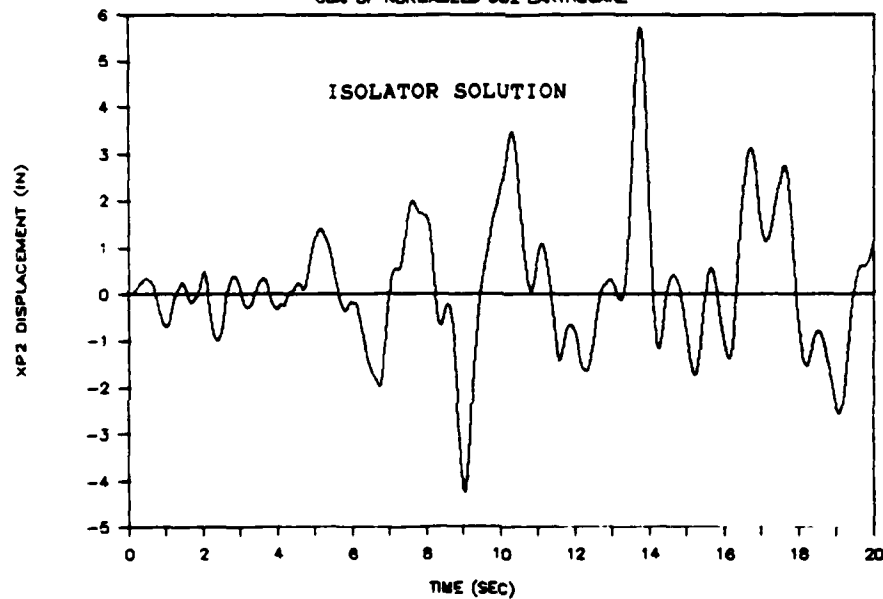
Both of the design solutions survive beyond the dry dock failure level; however, each of the designs have their own advantages and disadvantages. Figure (9.3) is a comparison between the keel block displacements for the wale shore solution and the isolator solution when excited by their respective design earthquakes. It is evident from this figure that the wale shore solution virtually prevents the submarine from moving horizontally relative to the dock floor. The isolator solution allows relatively large horizontal displacements to occur. Figure (9.4) is a comparison of the rotation of these two systems. Again, the wale shores are reducing movement.

The primary difference between the two design solutions is illustrated in figure (9.5). This figure is a comparison between the side block horizontal forces experienced by each solution. As seen in this figure, the wale shore system experiences forces which are an order of magnitude higher than those seen by the isolator solution.

SYSTEM #51 X1 VS TIME  
72% OF 1940 EL CENTRO EARTHQUAKE



SYSTEM #893 X1 VS TIME  
63% OF NORMALIZED DD2 EARTHQUAKE

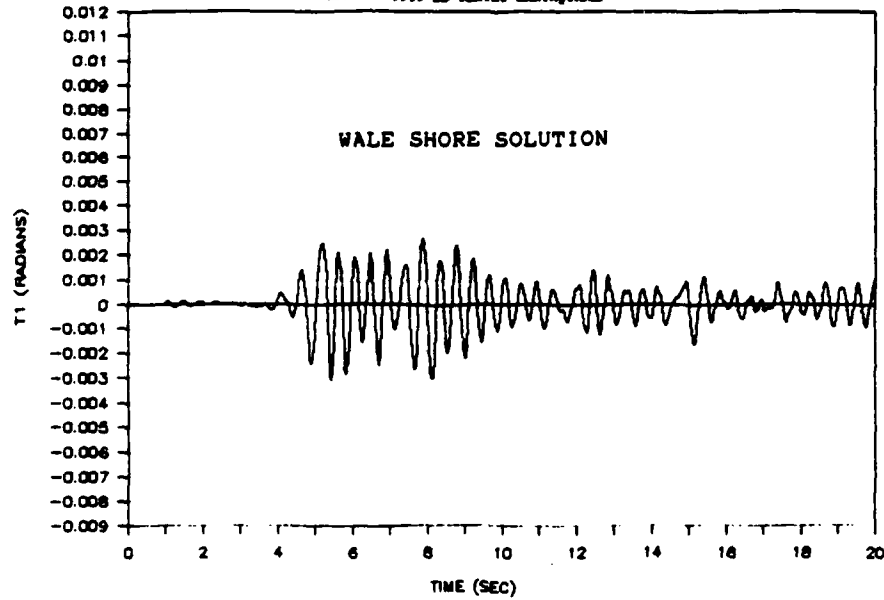


Keel Block Horizontal Displacement  
vs. Time Comparison  
High Stiffness Solution  
and Low Stiffness Solution

Figure 9.3

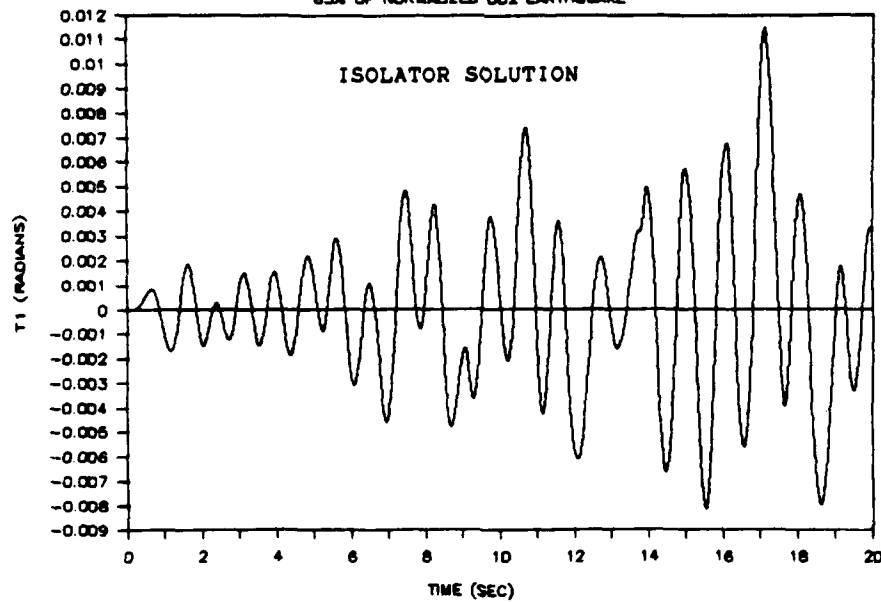
# SYSTEM # 51 T1 VS TIME

72% OF 1940 EL CENTRO EARTHQUAKE



# SYSTEM # 893 T1 VS TIME

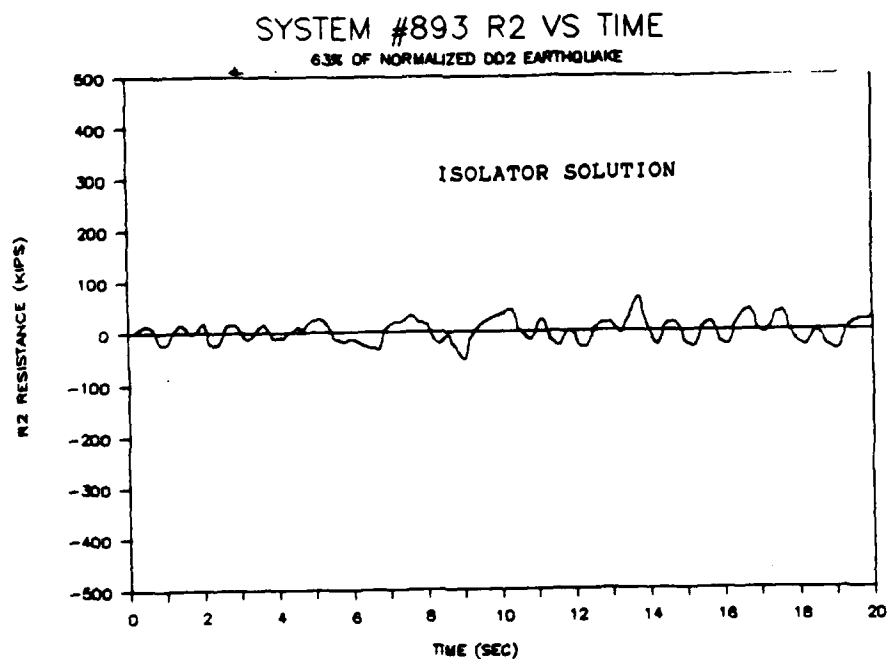
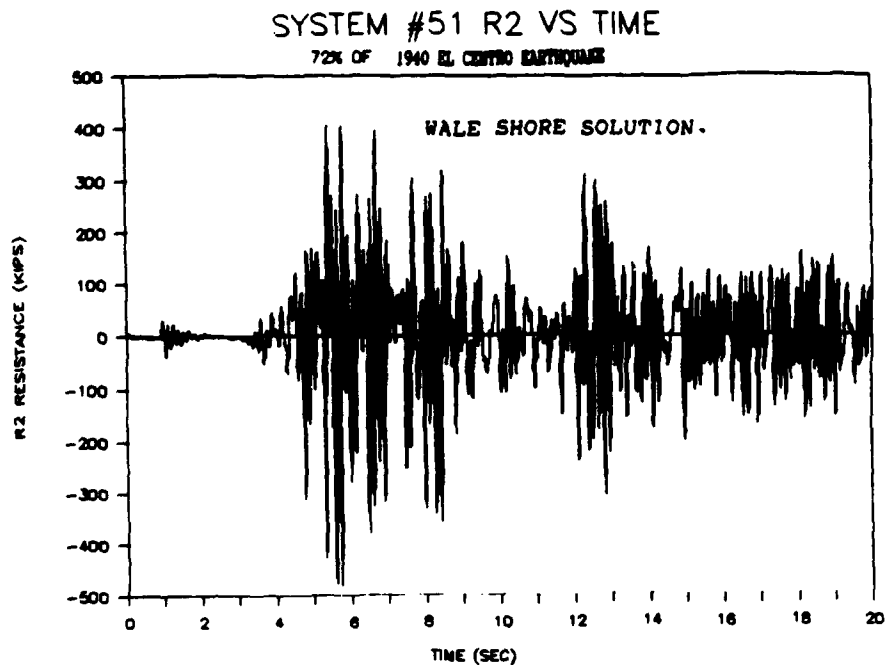
63% OF NORMALIZED D02 EARTHQUAKE



Rotation vs. Time Comparison  
High Stiffness Solution  
and Low Stiffness Solution

Figure 9.4





Side Block Horizontal Force vs.  
Time Comparison  
High Stiffness Solution  
and Low Stiffness Solution

Figure 9.5

The forces seen by the wale shore solution are also much more abrupt and higher in frequency. As expected, the wale shore solution very closely follows the earthquake. The wale shore high stiffness solution almost rigidly attaches the submarine to the dry dock. Therefore, personnel and equipment inside the submarine will experience the full acceleration magnitudes of the earthquake.

The isolator solution nearly uncouples the submarine from the dry dock so that the submarine remains almost fixed in space while the dry dock vibrates beneath. The accelerations experienced by the submarine are an order of magnitude less than the earthquake accelerations. This substantially improves the safety of personnel and equipment inside the submarine. Even though submarines are designed to withstand large shock factors, when a submarine is in dry dock much of its equipment and machinery may be open for repairs. In addition, the shocks accompanying an earthquake may last well over one minute as opposed to the very short duration of an explosion shock wave.

Both of the design solutions can be constructed; however, there are some cost and interference concerns. The wale shore solution will interfere with access to the dry dock to some degree, although the wale shores could be used as utility runs and staging platforms. This solution's impact on the dry dock itself is non-trivial. The installation of 28 hinge

assemblies along the dockside will be a major dry dock modification. In addition, the steel carriage and dry dock floor attachment fixtures are major changes to current drydocking practices and will require significant design and construction efforts.

Most of the modifications required to the blocking system and dry dock are within the capability of shipyards to accomplish. After a drydocking evolution has been completed, many additional manhours will be required to install the wale shores. One wale shore per side can be removed for production reasons while still meeting the survivability criteria. The use of the steel carriage and rubber caps might reduce the hours required to layout a blocking system. The measurements of the system would be locked into the construction, and it would be easier and faster to assemble this blocking system with cranes. The use of rubber and steel in the blocking system is much more reliable than the present oak and Douglas fir.

The isolator solution may be the more expensive solution due to the large number and high cost of the dynamic isolators. However, this solution offers less production interference and a substantial increase in submarine personnel and equipment safety. The actual blocking system size increase will be limited to the cross-connections of the steel carriage, but significant changes will still be required to

the dock floor to allow rigid attachment. Again, the use of the steel carriage and rubber caps should reduce the layout time of the drydock blocking system. Even though the submarine may move up to six inches horizontally during an earthquake using isolators, this motion is acceptable if appropriate precautions are taken in rigging services and platforms.

Considering the almost certain occurrence of a major earthquake in the proximity of a U.S. Naval shipyard where submarines can be drydocked within the next 20 years, the expeditious incorporation of one of these design solutions into U.S. Navy drydocking standards is strongly recommended.

## 9.2 Recommendations for Further Study

It is highly recommended that the following areas be investigated to further verify the feasibility of the proposed designs:

1. Study the effect of the wide range of existing wood blocking material properties on pier stiffness using statistical analysis.
2. Conduct additional tests on wood blocking materials to determine their properties when loaded at angles to the grain normally seen in a blocking system.

3. Conduct tests on rubber cap material in order determine its stiffness and rigidity behavior under biaxial loading.
4. The specific dynamic isolator and the associated sliders required for the low stiffness solution need to be designed in detail.
5. The steel carriage assembly for both solutions needs to be designed.
6. The required dry dock structural modifications need to be determined.
7. The design solutions need to be verified using model tests employing shaker tables and scale models.
8. A detailed earthquake site specific study needs to be accomplished. This would include the instrumentation of all graving docks susceptible to earthquakes in order to increase the data base. The proposed designs should be checked against a full range of different earthquake acceleration time histories.
9. Surface ship blocking systems need further examination. This should include modeling the flexibility inherent in surface ships. The problem of surface ship's significant longitudinal block loading distribution should also be taken into account.

10. The final design solution for use in Navy dry docks should also take into account the longitudinal excitation and response of the blocking system.

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15. Information in enclosure to letter from Tingley K. Lew, Structures Division Code L51, Naval Civil Engineering Laboratory, Port Hueneme, California, to LCDR Richard D. Hepburn, M.I.T. Graduate Student, 19 January 1988.
16. Telephone conversation between Ian G. Buckle, Vice President for Engineering Dynamic Isolation Systems Incorporated, Berkeley, California, and LCDR Richard D. Hepburn, M.I.T. Graduate Student, January 1988.
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## APPENDIX 1

1. "3DOFRUB" Computer Program Listing
2. "ACCLINPT", "BILINALL", "RUBBER", and  
"RESPALL" Subroutine Listings
3. Sample Input Data File and Output File

# "3DOFRUB" Computer Program Listing

Page 1  
03-11-88  
18:50:34

```

D Line# 1      7      Microsoft FORTRAN77 V3.20 02/84
1
2 $title: '3DOFRUB'
3 $nofloatcalls
4 $storage: 2
5
6 C-----
7
8 C      NON-LINEAR THREE DEGREE OF FREEDOM SYSTEM RESPONSE
9 C      USING FOURTH ORDER RUNGE-KUTTA METHOD
10 C      AND BILINEAR VERTICAL & HORIZONTAL STIFFNESSES
11 C      WITH HORZ/VERT ACCELERATION INPUT
12 C      AND DISPLACEMENT OUTPUT FILES
13 C      (INCLUDES WALE SHORE EFFECTS & HIGH BUILDUPS
14 C      AND THE USE OF RUBBER CAPS)
15
16 C-----
17
18
19      integer NN,l,mm,n,hull,nsys,flag10,ll
20      integer flag1,flag2,flag3,flag4,flag5,flag6,flag7,flag8
21      integer KY1,KY2,KY3,KY4,WWW1,YYY1,UUU1,WWW2,YYY2,UUU2,WWW3,YYY3
22      integer UUU3,WWW4,YYY4,UUU4,UUU5,WWW5,YYY5,decr
23      real*8 beta,weight,h,lk,gravity,AAA,Ks,sidearea,keelarea,plside
24      real ac(2002),acv(2002),xx(2002),yy(2002),tt(2002),rrr(2002)
25      real*8 m(4,4),cx(4,4),k(4,4),ko(4,4),crit2,crit3
26      real*8 baseside,basekeel,htside,htkeel
27      real*8 dtau,maxx,maxt,maxy,timex,timet
28      real*8 rf1,rf2,rf3,hf1,hf2,hf3,ampacc,mass,ampacmax
29      real*8 kvs,kvk,kvvp,khs,khk,kshp,kkhp,kvsp,base,counter,time
30      real*8 time1,time2,time3,time4,time5,time6,time7,time8
31      real*8 x,t,y,xold,told,yold,XSCL(6)
32      real*8 bbb,ccc,w12,w1,w22,w2,w32,w3,model,mode3
33      real*8 mmx1,mmang1,mmx3,mmang3,crit4,alpha,LLL
34      real*8 timey,mmmm1,mmmm2,mmmm3,mmmm4
35      real*8 R,S,TAU,A(6),B(6),C(6),D(6),E(6),F(6),G(6),HH(6)
36      real*8 br,amp,plkeel,u1,u2,XPRIM,VEL
37      real*8 KU1,KD1,khkb,QD1,XEL1,XMAX1,XMIN1,RR1,ZZ1,WZ1,VEL1
38      real*8 KU2,KD2,khsb,QD2,XEL2,XMAX2,XMIN2,RR2,ZZ2,WZ2,YPRIM1
39      real*8 KU3,KD3,kvsb1,QD3,YEL1,YMAX1,YMIN1,RR3,ZZ3,WZ3,DELTA
40      real*8 KU4,KD4,kvsb2,YEL2,YMAX2,YMIN2,RR4,ZZ4,WZ4,YPRIM2,VEL2
41      real*8 KU5,KD5,kvkb,QD4,YEL3,YMAX3,YMIN3,RR5,ZZ5,WZ5,YPRIM3
42      CHARACTER*40 DEC,DECV,quake,quake,quake,vname
43      character*40 sbfname,aclname,outfname,vfname
44
45
46
47 C      READ IN VESSEL AND DRYDOCK DATA: VESSEL WEIGHT,KG,I(ABOUT KEEL),
48 C      TIME INCREMENT OF DATA POINTS,VERTICAL STIFFNESS OF SIDE AND
49 C      KEEL PIERS,HORIZONTAL STIFFNESS OF SIDE AND KEEL PIERS,
50 C      GAVITATIONAL CONSTANT,SIDE BLOCK BASE AND HEIGHT,
51 C      KEEL BLOCK BASE AND HEIGHT,
52 C      BLOCK-BLOCK AND BLOCK-HULL FRICTION COEFFICIENTS,
53 C      SIDE AND KEEL BLOCK'S PROPORTIONAL LIMIT,
54 C      SIDE PIER-VESSEL CONTACT AREA,KEEL PIER-VESSEL CONTACT AREA,
55 C      CAP BLOCK INCLINATION ANGLE.
56
57 C      OPEN INPUT FILES AND READ DATA
58
59      write(*, '(a)') ' ENTER SHIP/BUILDUP FILE NAME ... '

```

```

D Line# 1      7
60      read(*,'(a)') sbfname
61
62      open(4,file= sbfname,status='old',form='formatted')
63
64      read(4,*) weight,h,Ik,kvs,kvsp,kvk,AAA,Ks
65      read(4,*) khs,khk,kshp,kkhp,QD1,QD2,QD3,gravity
66      read(4,*) baseside, basekeel,htside,htkeel,u1,u2
67      read(4,*) br,plside,plkeel,sidearea,keelarea,zeta
68      read(4,*) hull,nsys,beta,QD4,kvvp
69      CLOSE (4)
70
71      write(*,*) 'DO YOU WANT RESPONSE OUTPUT FILES? (Y OR N)'
72      read(*,'(a)') dec
73      if (dec.eq.'Y'.or.dec.eq.'y') then
74          write(*,*) 'INPUT DESIRED RESISTANCE OUTPUT: (1,2,3,4,5)'
75          write(*,*) 'KEEL HORIZONTAL FORCE = 1'
76          write(*,*) 'SIDE BLOCK HORIZONTAL FORCE = 2'
77          write(*,*) 'LEFT SIDE BLOCK VERT FORCE = 3'
78          write(*,*) 'RIGHT SIDE BLOCK VERT FORCE = 4'
79          write(*,*) 'KEEL BLOCK VERTICAL FORCE = 5'
80          read(*,*) decrr
81          endif
82
83      do 12,i=1,3
1 84      do 13,j=1,3
2 85      m(i,j)=0.0
2 86      k(i,j)=0.0
2 87      cx(i,j)=0.0
2 88      ko(i,j)=0.0
2 89 13      continue
1 90 12      continue
91
92
93 C      CALCULATE SYSTEM PARAMETERS
94
95      mass=weight/gravity
96      LLL=sqrt((htside-htkeel)**2D0+(br/2D0)**2D0)
97      alpha=asin((htside-htkeel)/LLL)
98
99      m(1,1)=mass
100      m(1,3)=h*mass
101      m(2,2)=mass
102      m(3,1)=mass*h
103      m(3,3)=Ik
104
105      k(1,1)=(2D0*Ks+2D0*khs+khk)
106      k(1,3)=(2D0*Ks*AAA+2D0*khs*LLL*sin(alpha))
107      k(3,1)=k(1,3)
108      k(2,2)=(2D0*kvs+kvk)
109      k(3,3)=(2D0*Ks*AAA**2D0+2D0*khs*((LLL*sin(alpha))**2D0)+
110 + (2D0*kvs*((LLL*cos(alpha))**2D0)-(weight*h)))
111      ko(1,1)=k(1,1)
112      ko(1,3)=k(1,3)
113      ko(3,1)=k(3,1)
114      ko(2,2)=k(2,2)
115      ko(3,3)=k(3,3)
116
117 C      DETERMINE NATURAL FREQUENCIES OF SYSTEM
118      bbb=-(m(1,1)*k(3,3)+m(3,3)*k(1,1)-m(1,3)*k(3,1)-m(3,1)*k(1,3))

```

```

D Line# 1      7      Microsoft FORTRAN77 V3.20 02/84
119      + /(m(1,1)*m(3,3)-m(1,3)*m(3,1))
120      ccc=(k(1,1)*k(3,3)-k(1,3)*k(3,1))/(m(1,1)*m(3,3)-m(1,3)*m(3,1))
121 C
122
123 C      NATURAL FREQ. MODE #1
124
125      w12=(-bbb-sqrt(bbb**2-4D0*ccc))/2D0
126      w1=sqrt(w12)
127
128 C      NATURAL FREQ. MODE #2
129
130      w22=k(2,2)/m(2,2)
131      w2=sqrt(w22)
132 C      NATURAL FREQ. MODE #3
133
134      w32=(-bbb+sqrt(bbb**2-4D0*ccc))/2D0
135      w3=sqrt(w32)
136
137 C      MODE SHAPE #1 & #3
138
139      mode1=(m(1,3)*w12-k(1,3))/(-m(1,1)*w12+k(1,1))
140      mode3=(m(1,3)*w32-k(1,3))/(-m(1,1)*w32+k(1,1))
141 C      DETERMINE C11,C13,C31,C33
142      mmx1=m(1,1)+m(1,3)/mode1
143      mmang1=mode1*m(3,1)+m(3,3)
144      mmx3=m(1,1)+m(1,3)/mode3
145      mmang3=mode3*m(3,1)+m(3,3)
146      mmmmm1=2D0*zeta*mmx1*w1
147      mmmmm2=2D0*zeta*mmx3*w3
148      mmmmm3=2D0*zeta*mmang1*w1
149      mmmmm4=2D0*zeta*mmang3*w3
150
151
152
153
154
155      cx(1,3)=(mmmm1-mmmm2)/(1/mode1-1/mode3)
156      cx(1,1)=mmmm1-(cx(1,3)/mode1)
157      cx(2,2)=2D0*zeta*m(2,2)*w2
158      cx(3,1)=(mmmm3-mmmm4)/(mode1-mode3)
159      cx(3,3)=mmmm3-(cx(3,1)*mode1)
160
161
162 C      READ IN ACCELERATION DATA
163
164      CALL ACCLINPT(amp,ac,acv,dtau,quakname,hname,vname)
165
166 C      ESTABLISH FAILURE CRITERIA AND FLAGS
167
168      crit2=min (u1,u2)
169      crit3= (6.6D-1*baseside-1.2D1)/htside
170      crit4=basekeel/(6D0*htkeel)
171      ampacc=1D0
172      counter=0.0
173      ampacmax=0.0
174 10000 continue
175      write(*,*) ampacc
176      flag1=0
177      flag2=0

```

```

D Line# 1      7
178      flag3=0
179      flag4=0
180      flag5=0
181      flag6=0
182      flag7=0
183      flag8=0
184      flag10=0
185      maxx=0.0
186      maxt=0.0
187      maxy=0.0
188      mm=0
189      x=0.0
190      y=0.0
191      t=0.0
192      xold=0.0
193      yold=0.0
194      told=0.0
195      R=0.0
196      S=0.0
197      TAU=0.0
198
199 C      INITIALIZING BILINEAR VARIABLES
200
201 C      INITIALIZING DELTA
202
203      if (kvs.eq.kvsp) then
204          YEL1=0.0
205      elseif (kvs.ne.kvsp) then
206          YEL1=QD3/(kvs-kvsp)
207      endif
208      if (kvk.eq.kvkp) then
209          YEL3=0.0
210      elseif (kvk.ne.kvkp) then
211          YEL3=QD4/(kvk-kvkp)
212      endif
213      DELTA=weight/(2D0*kvs+kvk)
214      if (QD3.ge.0.0.or.QD4.ge.0.0) then
215          kvsb1=kvs
216          kvkb=kvk
217          goto 100
218      endif
219      if (DELTA.lt.YEL3.and.DELTA.lt.YEL1) then
220          kvsb1=kvs
221          kvkb=kvk
222      elseif (DELTA.ge.YEL3.or.DELTA.ge.YEL1) then
223          kvsb1=kvsp
224          kvkb=kvkp
225          DELTA=YEL3+(weight-(YEL3*(2D0*kvs+kvk)))/(2D0*kvsp+kvkp)
226      endif
227
228 100      continue
229
230 C      INITIALIZING KEEL HORIZONTAL STIFFNESS
231
232      KU1=khk
233      KD1=kkhp
234      khkb=KU1
235      if (QD1.eq.0.0) goto 101
236      KY1=0

```

```
D Line# 1      7
237      XEL1=QD1/(KU1-KD1)
238      XMAX1=0.0
239      XMIN1=0.0
240      RR1=0.0
241      ZZ1=0.0
242      WZ1=0.0
243      WWW1=0.0
244      YYY1=0.0
245      UUU1=0.0
246
247 101      continue
248
249 C      INITIALIZING SIDE BLOCK HORIZONTAL STIFFNESS
250
251      KU2=khs
252      KD2=kshp
253      khsb=KU2
254      if (QD2 .eq. 0.0) goto 102
255      KY2=0
256      XEL2=QD2/(KU2-KD2)
257      XMAX2=0.0
258      XMIN2=0.0
259      RR2=0.0
260      ZZ2=0.0
261      WZ2=0.0
262      WWW2=0.0
263      YYY2=0.0
264      UUU2=0.0
265
266 102      continue
267
268 C      INITIALIZING LEFT SIDE BLOCK VERTICAL STIFFNESS
269
270      KU3=kvs
271      KD3=kvsp
272      if (QD3 .eq. 0.0) goto 103
273      KY3=0
274      YMAX1=0.0
275      YMIN1=0.0
276      RR3=kvsb1*DELTA
277      ZZ3=0.0
278      WZ3=0.0
279      WWW3=0.0
280      YYY3=0.0
281      UUU3=0.0
282
283 103      continue
284
285 C      INITIALIZING RIGHT SIDE BLOCK VERTICAL STIFFNESS
286      KU4=kvs
287      KD4=kvsp
288      kvsb2=kvsb1
289      if (QD3 .eq. 0.0) goto 104
290      KY4=0
291      YEL2=YEL1
292      YMAX2=0.0
293      YMIN2=0.0
294      RR4=kvsb2*DELTA
295      ZZ4=0.0
```

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D Line# 1      7
296      WZ4=0.0
297      WWW4=0.0
298      YYY4=0.0
299      UUU4=0.0
300
301 104      continue
302
303 C      INITIALIZING KEEL VERTICAL STIFFNESS
304
305      KU5=kvk
306      KD5=kvkp
307      if (QD4.eq.0.0) goto 105
308      KY5=0
309      YMAX3=0.0
310      YMIN3=0.0
311      RR5=kvkb*DELTA
312      ZZ5=0.0
313      WZ5=0.0
314      WWW5=0.0
315      YYY5=0.0
316      UUU5=0.0
317
318 105      continue
319
320 C      IMPLEMENTATION OF EQUATIONS OF MOTION INTO THE
321 C      RUNGE-KUTTA FORMULUS
322
323      do 301,1=1,2000
324
1 325 C      CALCULATE BILINEAR STIFFNESS AND RESISTANCE
1 326
1 327 C      CALCULATE KEEL HORIZONTAL BILINEAR STIFFNESS
1 328
1 329      if (QD1 .eq. 0.0) goto 106
1 330
1 331      CALL BILINALL(x,S,khkb,RR1,KD1,QD1,KU1,XEL1,XMAX1,XMIN1,
1 332      + KY1,ZZ1,WZ1,WWW1,YYY1,UUU1)
1 333
1 334 106      continue
1 335
1 336 C      CALCULATE SIDE BLOCK HORIZONTAL BILINEAR STIFFNESS
1 337
1 338      XPRIM=+x+LLL*t*sin(alpha)
1 339
1 340      if (QD2 .eq. 0.0) goto 107
1 341
1 342      VEL=+S+LLL*TAU*sin(alpha)
1 343
1 344      CALL BILINALL(XPRIM,VEL,khsb,RR2,KD2,QD2,KU2,XEL2,XMAX2,XMIN2,
1 345      + KY2,ZZ2,WZ2,WWW2,YYY2,UUU2)
1 346
1 347 107      continue
1 348
1 349 C      CALCULATE LEFT SIDE BLOCK VERTICAL BILINEAR STIFFNESS
1 350
1 351      YPRIM1=-y-t*LLL*cos(alpha)+DELTA
1 352
1 353      if (QD3 .eq. 0.0) goto 108
1 354      if (QD3 .gt. 0.0) then

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D Line# 1      7
1 355
1 356      VEL1=-R-TAU*LLL*cos(alpha)
1 357
1 358      CALL BILINALL(YPRIM1,VEL1,kvsb1,RR3,KD3,QD3,KU3,YEL1,YMAX1,
1 359      + YMIN1,KY3,ZZ3,WZ3,WWW3,YYY3,UUU3)
1 360
1 361      elseif (QD3 .lt. 0.0) then
1 362
1 363      CALL RUBBER(YPRIM1,kvsb1,RR3,KD3,QD3,KU3,YEL1)
1 364
1 365      endif
1 366
1 367 108      continue
1 368
1 369 C      CALCULATE RIGHT SIDE BLOCK VERTICAL BILINEAR STIFFNESS
1 370
1 371      YPRIM2=-y+t*LLL*cos(alpha)+DELTA
1 372
1 373      if (QD3 .eq. 0.0) goto 109
1 374      if (QD3 .gt. 0.0) then
1 375
1 376      VEL2=-R+TAU*LLL*cos(alpha)
1 377
1 378      CALL BILINALL(YPRIM2,VEL2,kvsb2,RR4,KD4,QD3,KU4,YEL2,YMAX2,
1 379      + YMIN2,KY4,ZZ4,WZ4,WWW4,YYY4,UUU4)
1 380
1 381      elseif (QD3 .lt. 0.0) then
1 382
1 383      CALL RUBBER(YPRIM2,kvsb2,RR4,KD4,QD3,KU4,YEL2)
1 384
1 385      endif
1 386
1 387 109      continue
1 388
1 389 C      CALCULATE KEEL VERTICAL STIFFNESS
1 390
1 391      YPRIM3=-y+DELTA
1 392
1 393      if (QD4 .eq. 0.0) goto 110
1 394      if (QD4 .gt. 0.0) then
1 395
1 396      CALL BILINALL(YPRIM3,-R,kvkb,RR5,KD5,QD4,KU5,YEL3,YMAX3,
1 397      + YMIN3,KY5,ZZ5,WZ5,WWW5,YYY5,UUU5)
1 398
1 399      elseif (QD4 .lt. 0.0) then
1 400
1 401      CALL RUBBER(YPRIM3,kvkb,RR5,KD5,QD4,KU5,YEL3)
1 402
1 403      endif
1 404
1 405 110      continue
1 406
1 407
1 408 C      RECALCULATION OF DELTA
1 409
1 410      if (QD3.ge.0.0.or.QD4.ge.0.0) then
1 411          DELTA=weight/(2D0*kvs+kvk)
1 412          goto 120
1 413      endif

```

3DOFRUB

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D Line# 1      7
1 414          if (kvkb.eq.kvk) then
1 415              DELTA=weight/(2D0*kvs+kvk)
1 416          elseif (kvkb.gt.kvk) then
1 417              DELTA=YEL3+(weight-(YEL3*(2D0*kvs+kvk)))/(2D0*kvsp+kvkp)
1 418          endif
1 419
1 420 120        continue
1 421
1 422          if (QD1.eq.0.0.and.QD2.eq.0.0.and.QD3.eq.0.0.
1 423      + and.QD4.eq.0.0) goto 111
1 424
1 425 C          RECALCULATION OF STIFFNESS MATRIX VALUES
1 426
1 427          k(1,1)=(2D0*Ks+2D0*khsb+khkb)
1 428          k(1,3)=(2D0*Ks*AAA+2D0*khsb*LLL*sin(alpha))
1 429          k(3,1)=k(1,3)
1 430          k(2,2)=(kvsb1+kvsb2+kvkb)
1 431          k(3,3)=(2D0*Ks*AAA**2D0+2D0*khsb*((LLL*sin(alpha))**2D0)+
1 432      + ((kvsb1+kvsb2)*((LLL*cos(alpha))**2D0)-(weight*h)))
1 433
1 434 111        DO 3000,11=0,5
2 435            A(11)=0.0
2 436            B(11)=0.0
2 437            C(11)=0.0
2 438            D(11)=0.0
2 439            E(11)=0.0
2 440            F(11)=0.0
2 441            G(11)=0.0
2 442            HH(11)=0.0
2 443 3000      CONTINUE
1 444            mm=mm+1
1 445            DO 302, NN=1,4
2 446                IF(NN.EQ.1) THEN
2 447                    FF=0.0
2 448                ELSE IF (NN.EQ.2 .OR. NN.EQ.3) THEN
2 449                    FF=5D-1
2 450                ELSE IF (NN.EQ.4) THEN
2 451                    FF=1D0
2 452                ENDIF
2 453                A(NN)=dtau*(R+FF*D(NN-1))
2 454                B(NN)=dtau*(S+FF*E(NN-1))
2 455                C(NN)=dtau*(TAU+FF*F(NN-1))
2 456                D(NN)=dtau*((-cx(2,2)/m(2,2))*(R+FF*D(NN-1))-(k(2,2)/m(2,2))
2 457      + ((y+FF*A(NN-1))-amp*ampacc*acv(1)/2.54D0)
2 458                G(NN)=dtau*((-cx(1,1)/m(1,1))*(S+FF*E(NN-1))-(cx(1,3)/m(1,1))
2 459      + ((TAU+FF*F(NN-1))-(k(1,1)/m(1,1))*(x+FF*B(NN-1))
2 460      + -(k(1,3)/m(1,1))*(t+FF*C(NN-1))-ampacc*ac(1)/2.54D0)
2 461                HH(NN)=dtau*((-cx(3,3)/m(3,3))*(TAU+FF*F(NN-1))-(cx(3,1)/m(3,3))
2 462      + ((S+FF*E(NN-1))-(k(3,3)/m(3,3))*(t+FF*C(NN-1))+(m(3,1)/m(3,3))
2 463      + ((-cx(2,2)/m(2,2))*(R+FF*D(NN-1))-(k(2,2)/m(2,2))*(y+FF*A(NN-
2 464      + 1)))*(t+FF*C(NN-1))
2 465      + -(k(3,1)/m(3,3))*(x+FF*B(NN-1))
2 466      + -(m(3,1)/m(3,3))*ampacc*ac(1)/2.54D0)
2 467
2 468                E(NN)=(m(1,1)*m(3,3)*G(NN)-m(1,3)*m(3,3)*HH(NN))/
2 469      + (m(3,3)*m(1,1)-m(1,3)*m(3,1))
2 470                F(NN)=(HH(NN)-(m(3,1)/m(3,3))*E(NN))
2 471 302        continue
1 472

```

```

D Line# 1      7
1 473 C      DETERMINING SYSTEM RESPONSE
1 474
1 475      yold=y
1 476      y=yold+(A(1)+2D0*A(2)+2D0*A(3)+A(4))/6D0
1 477
1 478      xold=x
1 479      x=xold+(B(1)+2D0*B(2)+2D0*B(3)+B(4))/6D0
1 480
1 481      told=t
1 482      t=told+(C(1)+2D0*C(2)+2D0*C(3)+C(4))/6D0
1 483
1 484      R=R+(D(1)+2D0*D(2)+2D0*D(3)+D(4))/6D0
1 485
1 486      S=S+(E(1)+2D0*E(2)+2D0*E(3)+E(4))/6D0
1 487
1 488      TAU=TAU+(F(1)+2D0*F(2)+2D0*F(3)+F(4))/6D0
1 489
1 490 C      MAXIMUM VALUES FOR TRANSLATIONS AND ROTATION
1 491
1 492      if (abs(xold).gt.abs(maxx)) then
1 493          timex=dttau*(1-1)
1 494          maxx=xold
1 495      endif
1 496      if (abs(told).gt.abs(maxt)) then
1 497          timet=dttau*(1-1)
1 498          maxt=told
1 499      endif
1 500      if (abs(yold).gt.abs(maxy)) then
1 501          timey=dttau*(1-1)
1 502          maxy=yold
1 503      endif
1 504
1 505 C      CALCULATE VERTICAL AND HORIZONTAL FORCES CAUSED BY VESSEL,
1 506 C      TEST FOR FAILURE
1 507
1 508 C      CALCULATE FORCES ON SIDE/KEEL BLOCKS
1 509      if (QD3.eq.0.0) then
1 510          rf1=kvs*((weight/k(2,2))-yold-(LLL*cos(alpha))*told)
1 511          rf2=kvs*((weight/k(2,2))-yold+(LLL*cos(alpha))*told)
1 512      elseif (QD3.ne.0.0) then
1 513          rf1=RR3
1 514          rf2=RR4
1 515      endif
1 516
1 517      if (QD4.eq.0.0) then
1 518          rf3=kvk*((weight/k(2,2))-yold)
1 519      elseif (QD4.ne.0.0) then
1 520          rf3=RR5
1 521      endif
1 522
1 523      if (QD2.eq.0.0) then
1 524          hf1=khs*(xold+LLL*told*sin(alpha))
1 525          hf2=khs*(xold+LLL*told*sin(alpha))
1 526      elseif (QD2.gt.0.0) then
1 527          hf1=RR2
1 528          hf2=RR2
1 529      endif
1 530
1 531      if (QD1.eq.0.0) then

```

```

D Line# 1      7
1 532      hf3=khk*(xold)
1 533      elseif (QD1.gt.0.0) then
1 534          hf3=RR1
1 535      endif
1 536
1 537 C      TEST FOR SIDE BLOCK SLIDING
1 538
1 539      if (flag1.eq.1) then
1 540          go to 400
1 541      else if (hf1.lt.0.0.and.rf1.gt.0.0
1 542      + .and. u1*rf1+hf1+u2*rf1*cos(beta)*sin(beta)
1 543      + -rf1*cos(beta)*sin(beta).lt.0.0) then
1 544          time1=dtau*(1-1)
1 545          flag1=1
1 546      else if (hf2.gt.0.0.and.rf2.gt.0.0
1 547      + .and. -u1*rf2+hf2-u2*rf2*(cos(beta)*sin(beta))
1 548      + +rf2*cos(beta)*sin(beta).gt.0.0) then
1 549          time1=dtau*(1-1)
1 550          flag1=1
1 551      endif
1 552      x1=xold
1 553      y1=yold
1 554      t1=told
1 555 400      continue
1 556
1 557 C      TEST FOR KEEL BLOCK SLIDING
1 558
1 559      if (flag2.eq.1) then
1 560          go to 410
1 561      else if (rf3.gt.0.0.and.abs(hf3/rf3).gt.crit2) then
1 562          time2=dtau*(1-1)
1 563          flag2=1
1 564      endif
1 565      x2=xold
1 566      y2=yold
1 567      t2=told
1 568 410      continue
1 569 C      TEST FOR SIDE BLOCK OVERTURNING
1 570
1 571      if (flag3.eq.1) then
1 572          go to 420
1 573      else if (hf1.lt.0.0.and.rf1.gt.0.0.and.abs(hf1/rf1).gt.crit3) then
1 574          time3=dtau*(1-1)
1 575          flag3=1
1 576      else if (hf2.gt.0.0.and.rf2.gt.0.0.and.abs(hf2/rf2).gt.crit3) then
1 577          time3=dtau*(1-1)
1 578          flag3=1
1 579      endif
1 580      x3=xold
1 581      y3=yold
1 582      t3=told
1 583 420      continue
1 584
1 585 C      TEST FOR KEEL BLOCK OVERTURNING
1 586
1 587      if (flag4.eq.1) then
1 588          go to 430
1 589      else if (rf3.gt.0.0.and.abs(hf3/rf3).gt.crit4) then
1 590          time4=dtau*(1-1)

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D Line# 1      7
1 591      flag4=1
1 592      endif
1 593      x4=xold
1 594      y4=yold
1 595      t4=told
1 596 430    continue
1 597
1 598 C      TEST FOR SIDE BLOCK LIFTOFF
1 599
1 600      if (flag5.eq.1) then
1 601          go to 440
1 602      else if (rf1.lt.0.0 .or. rf2.lt.0.0) then
1 603          time5=dtau*(1-1)
1 604          flag5=1
1 605      endif
1 606      x5=xold
1 607      y5=yold
1 608      t5=told
1 609 440    continue
1 610
1 611 C      TEST FOR KEEL BLOCK LIFTOFF
1 612
1 613      if (flag6.eq.1) then
1 614          go to 450
1 615      else if (rf3.lt.0.0) then
1 616          time6=dtau*(1-1)
1 617          flag6=1
1 618      endif
1 619      x6=xold
1 620      y6=yold
1 621      t6=told
1 622 450    continue
1 623
1 624 C      TEST FOR SIDE BLOCK CRUSHING
1 625
1 626      if (flag7.eq.1) then
1 627          go to 460
1 628      else if (rf1.gt.0.0 .and. (rf1/sidearea).gt.plside) then
1 629          flag7=1
1 630          time7=dtau*(1-1)
1 631
1 632          else if (rf2.gt.0.0 .and. (rf2/sidearea).gt.plside) then
1 633              flag7=1
1 634              time7=dtau*(1-1)
1 635      endif
1 636      x7=xold
1 637      y7=yold
1 638      t7=told
1 639 460    continue
1 640
1 641 C      TEST FOR KEEL BLOCK CRUSHING
1 642
1 643      if (flag8.eq.1) then
1 644          go to 470
1 645      else if (rf3.gt.0.0 .and. (rf3/keelarea).gt.plkeel) then
1 646          flag8=1
1 647          time8=dtau*(1-1)
1 648      endif
1 649      x8=xold
```

```

D Line# 1      7
1      650      y8=yold
1      651      t8=told
1      652 470   continue
1      653
1      654 C     CAPTURE OF DISPLACEMENT, ROTATION & RESISTANCE OUTPUT:
1      655
1      656      if (dec.ne.'Y'.and.dec.ne.'y') goto 301
1      657      xx(mm)=xold
1      658      tt(mm)=told
1      659      goto (501,502,503,504,505),decrr
1      660 501   if (QD1.eq.0.0) then
1      661      rrr(mm)=hf3
1      662      elseif (QD1.gt.0.0) then
1      663      rrr(mm)=RR1
1      664      endif
1      665      yy(mm)=yold
1      666      goto 506
1      667 502   if (QD2.eq.0.0) then
1      668      rrr(mm)=hf1
1      669      elseif (QD2.gt.0.0) then
1      670      rrr(mm)=RR2
1      671      xx(mm)=XPRIM
1      672      endif
1      673      yy(mm)=yold
1      674      goto 506
1      675 503   if (QD3.eq.0.0) then
1      676      rrr(mm)=rf1
1      677      elseif (QD3.ne.0.0) then
1      678      rrr(mm)=RR3
1      679      endif
1      680      yy(mm)=YPRIM1
1      681      goto 506
1      682 504   if (QD3.eq.0.0) then
1      683      rrr(mm)=rf2
1      684      elseif (QD3.ne.0.0) then
1      685      rrr(mm)=RR4
1      686      endif
1      687      yy(mm)=YPRIM2
1      688      goto 506
1      689 505   if (QD4.eq.0.0) then
1      690      rrr(mm)=rf3
1      691      elseif (QD4.ne.0.0) then
1      692      rrr(mm)=RR5
1      693      endif
1      694      yy(mm)=YPRIM3
1      695
1      696 506   continue
1      697
1      698 301   continue
1      699
1      700      go to 999
1      701
1      702 60000 continue
1      703      if(dec.ne.'Y'.and.dec.ne.'y') then
1      704      write(*,'(A)') ' I AM FINISHING. '
1      705      goto 20000
1      706      endif
1      707
1      708 C     CREATION OF DISPLACEMENT, ROTATION, & RESISTANCE OUTPUT FILES:

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D Line# 1      7
709
710      CALL RESPALL(xx,yy,tt,rrr,dtau)
711
712 998      go to 20000
713
714 999      CONTINUE
715
716      if(ampacc.eq.1D0) then
717
718          write(*,'(a)') ' ENTER OUTPUT FILENAME ...'
719          read(*,'(a)') outfame
720          open(46,file=outfame,status='new',form='formatted')
721
722
723      write(46,4000) nsys
724 4000      format(1x,/,28x,'**** System ',I2,1x,'****')
725      write(46,4050) hull
726 4050      format(1x,/,30x,'** Hull ',I3,1x,'**')
727      write(46,4100)
728 4100      format(1x,/,28x,'* Ship Parameters *')
729      write(46,4150)
730 4150      format(1x,/,5x,'Weight',8x,'Moment of Inertia',9x,'K.G.')
731      write(46,4200) weight,1k,h
732 4200      format(1x,f8.1,1x,'kips',1x,f11.1,1x,'kips-in-sec2',
733      +3x,f6.1,1x,'ins')
734      write(46,4250)
735 4250      format(1x,/,26x,'* Drydock Parameters *')
736      write(46,4300)
737 4300      format(1x,/,1x,'Side Block Height',3x,'Side Block Width',
738      +3x,'Keel Block Height',3x,'Keel Block Width')
739      write(46,4350) htside,baseside,htkeel,basekeel
740 4350      format(2x,f6.1,1x,'ins',11x,f6.1,1x,'ins',11x,f6.1,1x,'ins',
741      +9x,f6.1,1x,'ins')
742      write(46,4400)
743 4400      format(1x,/,1x,'Side-to-Side Pier Distance',3x,'Wale Shore Ht.',
744      +3x,'Wale Shore Stiffness',2x,'Cap Angle')
745      write(46,4450) br,AAA,Ks,beta
746 4450      format(1x,t7,f6.1,1x,'ins',17x,f6.1,1x,'ins',8x,f8.1,1x,
747      + 'kips/in',1x,f5.3,1x,'rad')
748      write(46,4470)
749 4470      format(1x,/, ' 1Side Side Pier Contact Area'
750      +,3x,'Total Keel Pier Contact Area',6X,'kkhp')
751      write(46,4475) sidearea,keelarea,kkhp
752 4475      format(1x,8x,f11.1,1x,'in2',14x,f11.1,1x,'in2',10x,f7.1,1x,
753      + 'kips/in')
754      write(46,4500)
755 4500      format(1x,/,1x,'B/B Friction Coeff',3x,
756      + 'H/B Friction Coeff',5x,'kshp',10x,'kvsp')
757      write(46,4550) u1,u2,kshp,kvsp
758 4550      format(6x,f7.3,13x,f7.3,7x,f7.1,1x,'kips/in',1x,f7.1,1x,
759      + 'kips/in')
760      write(46,4600)
761 4600      format(1x,/,1x,'Side Pier Fail Stress Limit',4x,'Keel Pier'
762      +, ' Fail Stress Limit',6x,'kvkp')
763      write(46,4650) plside,plkeel,kvvp
764 4650      format(1x,10x,f7.3,1x,'kips/in2',15x,f7.3,1x,'kips/in2',
765      + 6x,f7.1,1x,'kips/in')
766      write(46,4700)
767 4700      format(1x,/,1x,'Side Pier Vertical Stiffness',3x,'Side Pier',

```

```

D Line# 1      7
768      + ' Horizontal Stiffness' )
769      write(46,4750) kvs,khs
770 4750      format(1x,3x,f11.1,1x,'kips/in',11x,f11.1,1x,'kips/in')
771      write(46,4775)
772 4775      format(1x,/,1x,'Keel Pier Vertical Stiffness',3x,
773      + 'Keel Pier Horizontal Stiffness')
774      write(46,4780) kvk,khk
775 4780      format(1x,3x,f11.1,1x,'kips/in',11x,f11.1,1x,'kips/in')
776      write(46,4782)
777 4782      format(1x,/,6x,'QD1',17x,'QD2',18x,'QD3',17x,'QD4')
778      write(46,4785) QD1,QD2,QD3,QD4
779 4785      format(2x,f8.1,1x,'kips',7x,f8.1,1x,'kips',8x,f8.1,1x,'kips',
780      + 7x,f8.1,1x,'kips')
781      write(46,4800)
782 4800      format(1x,/,20x,'* System Parameters and Inputs *')
783      write(46,4850) quakname
784 4850      format(1x,/,1x,'Earthquake Used is ',A40)
785      write(46,4852) hname
786 4852      format(1x,/,1x,'Horizontal acceleration input is ',A40)
787      write(46,4854) vname
788 4854      format(1x,/,1x,'Vertical acceleration input is ',A40)
789      write(46,4875)
790 4875      format(1x,20x,' Earthquake Acceleration Time History.')
791
792      write(46,4895)
793 4895      format(1x,/,1x,'Vertical/Horizontal Ground Acceleration Ratio'
794      + ',3x,'Data Time Increment')
795      write(46,4990) amp,dtau
796 4990      format(1x,10x,f6.3,t55,f6.3,1X,'sec')
797      write(46,4900)
798 4900      format(1x,/,1x,'Gravitational Constant',3x,'% System Damping')
799      write(46,4950) gravity,zeta*100.
800 4950      format(1x,7x,f6.2,1x,'in/sec2',10x,f6.2,1x,'%')
801      write(46,5000)
802 5000      format(1x,/,25x,'Mass Matrix',/)
803      do 5100 i=1,3
1 804      write(46,5050) m(i,1),m(i,2),m(i,3)
1 805 5050      format(1x,f15.4,5x,f15.4,5x,f15.4)
1 806 5100      continue
807      write(46,5200)
808 5200      format(1x,/,25x,'Damping Matrix',/)
809      do 5300 i=1,3
1 810      write(46,5250) cx(i,1),cx(i,2),cx(i,3)
1 811 5250      format(1x,f15.4,5x,f15.4,5x,f15.4)
1 812 5300      continue
813      write(46,5400)
814 5400      format(1x,/,25x,'Stiffness Matrix',/)
815      do 5500 i=1,3
1 816      write(46,5450) ko(i,1),ko(i,2),ko(i,3)
1 817 5450      format(1x,f15.4,5x,f15.4,5x,f15.4)
1 818 5500      continue
819      write(46,5700)
820 5700      format(1x,/)
821      WRITE(46,6000)
822 6000      FORMAT(1X,'Undamped Natural Frequencies',t35,'Mode #1',t50,
823      + 'Mode #2',t65,'Mode #3')
824      write(46,6001) w1,w3,w2
825 6001      format(1x,t31,f7.3,1x,'rad/sec',t46,f7.3,1x,'rad/sec',t62,f7.3,
826      + ' rad/sec')

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D Line# 1      7
827      WRITE(46,6002)
828 6002      FORMAT(1X,'Damped Natural Frequencies',t35,'Mode #1',t50,
829      +'Mode #2',t65,'Mode #3')
830      WRITE(46,6500) w1*sqrt(1-zeta**2),w3*sqrt(1-zeta**2),
831      +w2*sqrt(1-zeta**2)
832 6500      format(1x,t31,f7.3,1x,'rad/sec',t46,f7.3,1x,'rad/sec',t62,f7.3,
833      +' rad/sec')
834      endif
835
836      write(46,10500) ampacc*100,quakname
837 10500      format(1x,///,1x,'For Earthquake Acceleration of ',f6.2,' % '
838      +,'of the ',A40,/)
839
840      write(46,25000)
841 25000      format(1x,'Maximums/Failures',t26,'X (ins)',t36,'Y (ins)',t51,
842      +'Theta (rads)',t65,'Time (sec)')
843      write(46,25001)
844 25001      format(1x,'-----',t25,'-----',t35,'-----',t50,
845      +'-----',t64,'-----')
846      write (46,310) maxx,timex
847 310      format (1x,' Maximum X',t25,f9.6,t65,f5.2)
848      write (46,311) maxy,timey
849 311      format (1x,' Maximum Y',t35,f9.6,t65,f5.2)
850      write (46,312) maxt,timet
851 312      format (1x,' Maximum Rotation',t50,f9.6,t65,f5.2)
852
853      if (flag1.eq.1) then
854      flag10=flag10+1
855      write (46,313) x1,y1,t1,time1
856 313      format (1x,'Side block sliding' ,t25,f9.6,t35,f9.6,t50,f9.6,
857      +t65,f5.2)
858
859      endif
860
861      if (flag2.eq.1) then
862      flag10=flag10+1
863      write (46,314) x2,y2,t2,time2
864 314      format (1x,'Keel block sliding' ,t25,f9.6,t35,f9.6,t50,f9.6,
865      +t65,f5.2)
866      endif
867
868      if (flag3.eq.1) then
869      flag10=flag10+1
870      write (46,315) x3,y3,t3,time3
871 315      format (1x,'Side block overturning' ,t25,f9.6,t35,f9.6,t50,f9.6,
872      +t65,f5.2)
873      endif
874
875      if (flag4.eq.1) then
876      flag10=flag10+1
877      write (46,316) x4,y4,t4,time4
878 316      format (1x,'Keel block overturning' ,t25,f9.6,t35,f9.6,t50,f9.6,
879      +t65,f5.2)
880      endif
881
882      if (flag5.eq.1) then
883      flag10=flag10+1
884      write (46,317) x5,y5,t5,time5
885 317      format (1x,'Side block liftoff' ,t25,f9.6,t35,f9.6,t50,f9.6,

```



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D Line# 1      7      Microsoft FORTRAN77 V3.20 02/84
886      +t65,f5.2)
887      endif
888
889      if (flag6.eq.1) then
890      flag10=flag10+1
891      write (46,318) x6,y6,t6,time6
892 318      format (1x,'Keel block liftoff' ,t25,f9.6,t35,f9.6,t50,f9.6,
893      +t65,f5.2)
894      endif
895
896      if (flag7.eq.1) then
897      flag10=flag10+1
898      write (46,319) x7,y7,t7,time7
899 319      format (1x,'Side block crushing' ,t25,f9.6,t35,f9.6,t50,f9.6,
900      +t65,f5.2)
901      endif
902
903      if (flag8.eq.1) then
904      flag10=flag10+1
905      write (46,320) x8,y8,t8,time8
906 320      format (1x,'Keel block crushing' ,t25,f9.6,t35,f9.6,t50,f9.6,
907      +t65,f5.2)
908      endif
909
910      if(flag10.eq.0) then
911      write(46,11000)
912 11000      format(1x,/,1x,'No failures occurred.')
913      if(counter.eq.1.0 .and. flag10.eq.0) then
914      go to 60000
915      endif
916      if(counter.eq.0.0) then
917      ampaccmax=ampacc
918      ampacc=ampacc+1D-1
919      counter=1.0
920      write(*,'(A)') ' In secondary looping stage. '
921      endif
922      endif
923      if(ampacc.le.ampaccmax) go to 20000
924      if(counter.eq.1.0) then
925      ampacc=ampacc-1D-2
926      else if(counter.eq.0.0) then
927      ampacc=ampacc-1D-1
928      endif
929      go to 10000
930 20000      continue
931      stop
932      end

```

Name	Type	Offset	P Class
A	REAL*8	48946	
AAA	REAL*8	49082	
ABS			INTRINSIC
AC	REAL	32882	
ACLFNA	CHAR*40	*****	
ACV	REAL	40890	
ALPHA	REAL*8	49344	
AMP	REAL*8	49496	
AMPACC	REAL*8	49656	

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D Line# 1	7		
AMPACM	REAL*8	49672	
ASIN			INTRINSIC
B	REAL*8	48898	
BASE	REAL*8	*****	
BASEKE	REAL*8	49170	
BASESI	REAL*8	49162	
BBB	REAL*8	49352	
BETA	REAL*8	49258	
BR	REAL*8	49210	
C	REAL*8	32834	
CCC	REAL*8	49360	
COS			INTRINSIC
COUNTE	REAL*8	49664	
CRIT2	REAL*8	49632	
CRIT3	REAL*8	49640	
CRIT4	REAL*8	49648	
CX	REAL*8	32658	
D	REAL*8	32786	
DEC	CHAR*40	49282	
DECRR	INTEGER*2	49322	
DECV	CHAR*40	*****	
DELTA	REAL*8	49812	
DTAU	REAL*8	49504	
E	REAL*8	32562	
F	REAL*8	32610	
FF	REAL	50266	
FLAG1	INTEGER*2	49680	
FLAG10	INTEGER*2	49696	
FLAG2	INTEGER*2	49682	
FLAG3	INTEGER*2	49684	
FLAG4	INTEGER*2	49686	
FLAG5	INTEGER*2	49688	
FLAG6	INTEGER*2	49690	
FLAG7	INTEGER*2	49692	
FLAG8	INTEGER*2	49694	
G	REAL*8	32514	
GRAVIT	REAL*8	49154	
H	REAL*8	49042	
HF1	REAL*8	50318	
HF2	REAL*8	50326	
HF3	REAL*8	50334	
HH	REAL*8	32466	
HNAME	CHAR*40	49552	
HTKEEL	REAL*8	49186	
HTSIDE	REAL*8	49178	
HULL	INTEGER*2	49254	
I	INTEGER*2	49324	
IK	REAL*8	49050	
J	INTEGER*2	49326	
K	REAL*8	32338	
KD1	REAL*8	49844	
KD2	REAL*8	49924	
KD3	REAL*8	50004	
KD4	REAL*8	50068	
KD5	REAL*8	50148	
KEELAR	REAL*8	49242	
KHK	REAL*8	49106	
KHKB	REAL*8	49852	
KHS	REAL*8	49098	

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D Line# 1 7

KHSB	REAL*8	49932
KKHP	REAL*8	49122
KO	REAL*8	32210
KS	REAL*8	49090
KSHP	REAL*8	49114
KU1	REAL*8	49836
KU2	REAL*8	49916
KU3	REAL*8	49998
KU4	REAL*8	50060
KU5	REAL*8	50140
KVK	REAL*8	49074
KVKB	REAL*8	49828
KVKP	REAL*8	49274
KVS	REAL*8	49058
KVSB1	REAL*8	49920
KVSB2	REAL*8	50076
KVSP	REAL*8	49066
KY1	INTEGER*2	49860
KY2	INTEGER*2	49940
KY3	INTEGER*2	50012
KY4	INTEGER*2	50084
KY5	INTEGER*2	50156
L	INTEGER*2	50204
LL	INTEGER*2	50262
LLL	REAL*8	49336
M	REAL*8	32082
MASS	REAL*8	49328
MAXT	REAL*8	49706
MAXX	REAL*8	49698
MAXY	REAL*8	49714
MIN		
MM	INTEGER*2	49722
MMANG1	REAL*8	49440
MMANG3	REAL*8	49456
MMMM1	REAL*8	49464
MMMM2	REAL*8	49472
MMMM3	REAL*8	49480
MMMM4	REAL*8	49488
MMX1	REAL*8	49432
MMX3	REAL*8	49448
MODE1	REAL*8	49416
MODE3	REAL*8	49424
N	INTEGER*2	*****
NN	INTEGER*2	50264
NSYS	INTEGER*2	49256
OUTFNA	CHAR*40	50502
PLKEEL	REAL*8	49226
PLSIDE	REAL*8	49218
QD1	REAL*8	49130
QD2	REAL*8	49138
QD3	REAL*8	49146
QD4	REAL*8	49266
QUAKNA	CHAR*40	49512
R	REAL*8	49772
RF1	REAL*8	50294
RF2	REAL*8	50302
RF3	REAL*8	50310
RR1	REAL*8	49886
RR2	REAL*8	49966

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D Line# 1 7  
RR3 REAL\*8 50030  
RR4 REAL\*8 50110  
RR5 REAL\*8 50174  
RRR REAL 24074  
S REAL\*8 49780  
SBFNAM CHAR\*40 48994  
SIDEAR REAL\*8 49234  
SIN  
SQRT  
T REAL\*8 49740  
T1 REAL 50358  
T2 REAL 50378  
T3 REAL 50398  
T4 REAL 50418  
T5 REAL 50438  
T6 REAL 50458  
T7 REAL 50478  
T8 REAL 50498  
TAU REAL\*8 49788  
TIME REAL\*8 \*\*\*\*\*  
TIME1 REAL\*8 50342  
TIME2 REAL\*8 50362  
TIME3 REAL\*8 50382  
TIME4 REAL\*8 50402  
TIME5 REAL\*8 50422  
TIME6 REAL\*8 50442  
TIME7 REAL\*8 50462  
TIME8 REAL\*8 50482  
TIMET REAL\*8 50278  
TIMEX REAL\*8 50270  
TIMEY REAL\*8 50286  
TOLD REAL\*8 49764  
TT REAL 16066  
U1 REAL\*8 49194  
U2 REAL\*8 49202  
UUU1 INTEGER\*2 49914  
UUU2 INTEGER\*2 49994  
UUU3 INTEGER\*2 50058  
UUU4 INTEGER\*2 50138  
UUU5 INTEGER\*2 50202  
VEL REAL\*8 50214  
VEL1 REAL\*8 50230  
VEL2 REAL\*8 50246  
VFNAME CHAR\*40 \*\*\*\*\*  
VNAME CHAR\*40 49592  
W1 REAL\*8 49376  
W12 REAL\*8 49368  
W2 REAL\*8 49392  
W22 REAL\*8 49384  
W3 REAL\*8 49408  
W32 REAL\*8 49400  
WEIGHT REAL\*8 49034  
WWW1 INTEGER\*2 49910  
WWW2 INTEGER\*2 49990  
WWW3 INTEGER\*2 50054  
WWW4 INTEGER\*2 50134  
WWW5 INTEGER\*2 50198  
WZ1 REAL\*8 49902  
WZ2 REAL\*8 49982

INTRINSIC  
INTRINSIC

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D Line# 1 7
WZ3 REAL*8 50046
WZ4 REAL*8 50126
WZ5 REAL*8 50190
X REAL*8 49724
X1 REAL 50350
X2 REAL 50370
X3 REAL 50390
X4 REAL 50410
X5 REAL 50430
X6 REAL 50450
X7 REAL 50470
X8 REAL 50490
XEL1 REAL*8 49862
XEL2 REAL*8 49942
XMAX1 REAL*8 49870
XMAX2 REAL*8 49950
XMIN1 REAL*8 49878
XMIN2 REAL*8 49958
XOLD REAL*8 49748
XPRIM REAL*8 50106
XSCL REAL*8 16018
XX REAL 2
Y REAL*8 49732
Y1 REAL 50354
Y2 REAL 50374
Y3 REAL 50394
Y4 REAL 50414
Y5 REAL 50434
Y6 REAL 50454
Y7 REAL 50474
Y8 REAL 50494
YEL1 REAL*8 49796
YEL2 REAL*8 50086
YEL3 REAL*8 49804
YMAX1 REAL*8 50014
YMAX2 REAL*8 50094
YMAX3 REAL*8 50158
YMIN1 REAL*8 50022
YMIN2 REAL*8 50102
YMIN3 REAL*8 50166
YOLD REAL*8 49756
YPRIM1 REAL*8 50222
YPRIM2 REAL*8 50238
YPRIM3 REAL*8 50254
YY REAL 8010
YYY1 INTEGER*2 49912
YYY2 INTEGER*2 49992
YYY3 INTEGER*2 50056
YYY4 INTEGER*2 50136
YYY5 INTEGER*2 50200
ZETA REAL 49250
ZZ1 REAL*8 49894
ZZ2 REAL*8 49974
ZZ3 REAL*8 50038
ZZ4 REAL*8 50118
ZZ5 REAL*8 50182

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D Line# 1 7

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Name	Type	Size	Class
ACCLIN			SUBROUTINE
BILINA			SUBROUTINE
MAIN			PROGRAM
RESPAL			SUBROUTINE
RUBBER			SUBROUTINE

Pass One      No Errors Detected  
                 932 Source Lines

"ACCLINPT", "BILINALL", "RUBBER", and  
 "RESPALL" Subroutine Listings . . . . .

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D Line# 1 7 Microsoft FORTRAN77 V3.20 02/84

```

1
2 $title: 'acclinpt'
3 $storage: 2
4 $nofloatcalls
5
6
7 C-----
8
9 C    SUBROUTINE WHICH PROMPTS FOR AND READS IN HORIZONTAL
10 C    AND VERTICAL ACCELERATION TIME HISTORY FILES
11 C    AND THE TIME STEP AND EARTHQUAKE NAME
12
13 C-----
14
15    SUBROUTINE ACCLINPT(amp,ac,acv,dtau,quakname,hname,vname)
16    integer n
17    real ac(2002),acv(2002)
18    real*8 amp,dtau,dtauu,dtauu
19    character*40 acfname,vfname,decv,quakname,hname,vname
20    character*40 hquaknam,vquaknam
21
22 C    READ IN ACCELERATION DATA
23
24 C    HORIZONTAL ACCELERATION
25 700 write(*, '(a)') ' ENTER HORIZONTAL ACCELERATION FILE NAME...'
26    read(*, '(a)') acfname
27    open(44,file=acfname,status='old',form='formatted')
28    write(*, '(a)') ' READING HORIZONTAL ACCELERATION FILE...'
29    read(44, '(a)') hquaknam
30    read(44, '(a)') hname
31    read(44, '(f9.4)') dtauu
32    do 300,n=1,2000
1 33    read (44,*) ac(n)
1 34 300    continue
35
36 C    VERTICAL ACCELERATION
37 307 write(*, '(a)') ' WILL YOU USE A VERTICAL ACCELERATION FILE? '
38    write(*, '(a)') ' (Y/N) '
39    read(*, '(a)') decv
40    if (decv.eq. 'Y') then
41        write(*, '(a)') ' ENTER VERTICAL ACCELERATION FILE NAME...'
42        read(*, '(a)') vfname
43        open(45,file=vfname,status='old',form='formatted')
44        write(*, '(a)') ' READING VERTICAL ACCELERATION FILE...'
45        amp=1.0
46        read(45, '(a)') vquaknam
47        read(45, '(a)') vname
48        read(45, '(f9.4)') dtauu

```

```

49      if (dtauh .ne. dtauv .or. vquaknam .ne. hquaknam) then
50          write(*,'(a)') ' INCOMPATIBLE ACCELERATION FILES !!! '
51          write(*,'(a)') ' REINPUT COMPATIBLE FILES '
52          goto 700
53      endif
54      do 305,n=1,2000
1 55          read (45,*) acv(n)
1 56 305      continue
57      endif
58
59      if (decv.eq.'N') then
60          do 306,n=1,2000
1 61          acv(n)=ac(n)
1 62 306      continue
63          write(*,'(a)') ' INPUT DESIRED VERT/HORZ ACCEL RATIO: '
64          read(*,*) amp
65      endif
66
67      if (decv.ne.'Y' .and. decv.ne.'N') then
68          write(*,'(a)') ' TRY AGAIN '
69          goto 307
70      endif
71
72      quakname=hquaknam
73      dtau=dtauh
74      CLOSE (44)
75      CLOSE (45)
76
77      RETURN
78      END

```

Name	Type	Offset	P	Class
------	------	--------	---	-------

AC	REAL	4	*	
ACLFNA	CHAR*40	2		
ACV	REAL	8	*	
AMP	REAL*8	0	*	
DECV	CHAR*40	92		
DTAU	REAL*8	12	*	
DTAUH	REAL*8	82		
DTAUV	REAL*8	212		
HNAME	CHAR*40	20	*	
HQUAKN	CHAR*40	42		
N	INTEGER*2	90		
QUAKNA	CHAR*40	16	*	
VFNAME	CHAR*40	132		
VNAME	CHAR*40	24	*	
VQUAKN	CHAR*40	172		



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```
1 $debug
2 $title: 'bilinall'
3 $storage: 2
4 $nofloatcalls
5
6
7 C-----
8
9 C    SUBROUTINE WHICH CALCULATES THE BILINEAR HORIZONTAL
10 C    OR VERTICAL STIFFNESS AND RESISTANCE
11
12 C-----
13
14     SUBROUTINE BILINALL(U,V,PK,RR,KD,QD,KU,UEL,UMAX,UMIN,KY,ZZ,WZ,
15     + WWW,YYY,UUU)
16
17     real*8 U,V,RR,KD,QD,KU,UEL,PK
18     real*8 UMAX,UMIN,ZZ,WZ
19     integer WWW,YYY,UUU,KY
20
21 C    BEGINNING OF BILINEAR LOGIC
22
23 C    CHECK IF RESPONSE STILL ON INITIAL ELASTIC LINE
24
25     if (KY .lt. 0) goto 4040
26     if (KY .gt. 0) goto 3480
27     RR=KU*U
28     PK=KU
29
30 C    CHECK IF THE RESPONSE HAS GONE PLASTIC
31
32     if (U .gt. -UEL .and. U .lt. UEL) goto 4720
33
34 C    RESPONSE IS NOW PLASTIC
35
36     if (U .lt. -UEL) goto 4040
37
38 C    RESPONSE IS ON THE TOP PLASTIC LINE
39
40 3220    KY=1
41         PK=KD
42         RR=KD*U+QD
43         WWW=0
44         YYY=0
45         ZZ=0.0
46         goto 4720
47
```

```

48 C    CHECK IF VELOCITY SHIFTS FROM POSITIVE TO NEGATIVE
49
50 3480  if (V .gt. 0) goto 3720
51
52 C    CHECK IF ON THE RIGHT ELASTIC LINE
53
54      if (YYY .gt. 0) goto 3630
55
56 C    CALCULATE VALUE OF UMAX
57
58      ZZ=U
59 3630  YYY=1
60      UMAX=ZZ
61
62 C    CHECK IF RESPONSE SHIFTS TO LOWER PLASTIC LINE
63
64 3720  if (U .lt. (UMAX-2*UEL)) goto 4040
65
66 C    CHECK IF RESPONSE SHIFTS TO TOP PLASTIC LINE
67
68      if (U .gt. UMAX) goto 3220
69
70 C    CHECK IF RESPONSE RETURNS TO TOP PLASTIC LINE
71
72      if (YYY .eq. 0) goto 3220
73
74 C    RESPONSE IS ON THE RIGHT ELASTIC LINE
75
76      KY=1
77      PK=KU
78      RR=KU*U+(KD-KU)*UMAX+QD
79      goto 4720
80
81 C    CHECK IF VELOCITY SHIFTS TO POSITIVE
82
83 4040  if (V .gt. 0) goto 4350
84
85 C    CHECK IF RESPONSE REMAINS ELASTIC
86
87      if (WWW .eq. 1) goto 4350
88
89 C    RESPONSE IS ON THE BOTTOM PLASTIC LINE
90
91 4150  KY=-1
92      PK=KD
93      RR=KD*U-QD
94      UUU=0
95      WZ=0.0
96      goto 4720
97

```

```

98 C    CHECK IF RESPONSE IS ON THE LEFT ELASTIC LINE
99
100 4350  if (UUU .gt. 0) goto 4370
101      WZ=U
102 4370  UUU=1
103      UMIN=WZ
104
105 C    CHECK IF RESPONSE RETURNS TO TOP PLASTIC LINE
106
107      if (U .gt. (UMIN+2*UEL)) goto 3220
108
109 C    CHECK IF RESPONSE RETURNS TO BOTTOM PLASTIC LINE
110
111      if (U .lt. UMIN) goto 4150
112
113 C    RESPONSE IS ON THE LEFT ELASTIC LINE
114
115      WWW=1
116      RR=KU*U+(KD-KU)*UMIN-QD
117      PK=KU
118
119 4720  continue
120      RETURN
121      END

```

Name	Type	Offset	P Class
------	------	--------	---------

KD	REAL*8	16	*
KU	REAL*8	24	*
KY	INTEGER*2	40	*
PK	REAL*8	8	*
QD	REAL*8	20	*
RR	REAL*8	12	*
U	REAL*8	0	*
UEL	REAL*8	28	*
UMAX	REAL*8	32	*
UMIN	REAL*8	36	*
UUU	INTEGER*2	60	*
V	REAL*8	4	*
WWW	INTEGER*2	52	*
WZ	REAL*8	48	*
YYY	INTEGER*2	56	*
ZZ	REAL*8	44	*

Name	Type	Size	Class
------	------	------	-------

BILINA			SUBROUTINE
--------	--	--	------------

Pass One    No Errors Detected  
             121 Source Lines

D Line# 1 7 Microsoft FORTRAN77 V3.20 02/84

```

1 $debug
2 $title: 'rubber'
3 $nofloatcalls
4
5
6 C-----
7
8 C SUBROUTINE WHICH CALCULATES THE RUBBER CAP VERTICAL
9 C STIFFNESS AND RESISTANCE
10
11 C-----
12
13 SUBROUTINE RUBBER(U,PK,RR,KD,QD,KU,UCL)
14
15 real*8 U,RR,KD,QD,KU,UCL,PK
16
17 C BEGINNING OF RUBBER LOGIC
18
19 C CHECK IF RESPONSE STILL ON INITIAL ELASTIC LINE
20
21 if (U .gt. UCL) goto 3220
22 RR=KU*U
23 PK=KU
24 goto 4720
25
26 C RESPONSE IS ON THE 2ND ELASTIC LINE
27
28 3220 continue
29 PK=KD
30 RR=KD*U+QD
31
32 4720 continue
33 RETURN
34 END

```

Name	Type	Offset P Class
KD	REAL*8	12 *
KU	REAL*8	20 *
PK	REAL*8	4 *
QD	REAL*8	16 *
RR	REAL*8	8 *
U	REAL*8	0 *
UCL	REAL*8	24 *

D Line# 1 7

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```

1
2 $title: 'RESPALL'
3 $storage: 2
4 $nofloatcalls
5
6
7 C-----
8
9 C    SUBROUTINE WHICH CREATES VERTICAL, ROTATIONAL,
10 C    HORIZONTAL DISPLACEMENT AND DESIGNATED
11 C    RESISTANCE OUTPUT FILES
12
13 C-----
14
15     SUBROUTINE RESPALL(xx,yy,tt,rrr,dtau)
16     real xx(2002),tt(2002),yy(2002),rrr(2002)
17     real*8 dtau,time
18     character*40 xname,yname,tname,rrname
19     integer n
20
21 C    CREATION OF DISPLACEMENT & ROTATION OUTPUT FILES:
22
23     write(*, '(a)') ' ENTER X OUTPUT FILE NAME...'
24     read(*, '(a)') xname
25     open(47,file=xname,status='new',form='formatted')
26
27     write(*, '(a)') ' ENTER Y DISPL OUTPUT FILE NAME...'
28     read(*, '(a)') yname
29     open(48,file=yname,status='new',form='formatted')
30
31     write(*, '(a)') ' ENTER THETA OUTPUT FILE NAME...'
32     read(*, '(a)') tname
33     open(49,file=tname,status='new',form='formatted')
34
35     write(*, '(a)') ' ENTER RESISTANCE OUTPUT FILE NAME...'
36     read(*, '(a)') rrname
37     open(41,file=rrname,status='new',form='formatted')
38
39
40     do 308,n=1,2000
1 41         time=dtau*(n-1)
1 42         write(47,7000) time,xx(n)
1 43 7000         format(f7.3,10x,e13.6)
1 44
1 45         write(48,7010) time,yy(n)
1 46 7010         format(f7.3,10x,e13.6)

```

```

1  47
1  48      write(49,7020) time,tt(n)
1  49 7020      format(f7.3,10x,e13.6)
1  50
1  51      write(41,7030) time,rrr(n)
1  52 7030      format(f7.3,10x,e13.6)
1  53
1  54 308  CONTINUE
      55
      56      RETURN
      57      END

```

Name	Type	Offset	P	Class
DTAU	REAL*8	16	*	
N	INTEGER*2	162		
RRNAME	CHAR*40	122		
RRR	REAL	12	*	
TIME	REAL*8	164		
TNAME	CHAR*40	82		
TT	REAL	8	*	
XNAME	CHAR*40	2		
XX	REAL	0	*	
YNAME	CHAR*40	42		
YY	REAL	4	*	

58

Name	Type	Size	Class
RESPAL			SUBROUTINE

Pass One    No Errors Detected  
              58 Source Lines

# Sample Input Data File and Output File. .

\*\*\*SHIP/SUB DRYDOCK BLOCKING SYSTEM\*\*\* DATA FILE: A:SIOBILN.DAT

## \*\*\*INPUT FILE DATA\*\*\*

SHIP NAME: LAFAYETTE SSBN 616  
DISCRIPTION OF ISOLATORS IF USED: NO ISOLATOR ALL BILINEAR  
DISCRIPTION OF BUILDUP: 8 SPACING COMPOSITE  
DISCRIPTION OF MALE SHORES USED: NO MALE SHORES  
DISCRIPTION OF DAMPING: 5 % DAMPING  
LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION  
NAVSEA DOCKING DRAWING NUMBER: 845-2006640  
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: SIKHORIG.WK1 & SISHORIG.WK1  
MISC. COMMENTS: SIOBILN.DAT 1839 4 MAR 88

SHIP WEIGHT (KIPS)	W= 16369.9
HEIGHT OF KG (IN)	H= 193
MOMENT OF INERTIA (KIPS*IN*SEC^2)	Ik= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)	Kvs= 10113.39
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	Kvsp= 4025.64
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)	KVK= 46808.74
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)	KVKP= 46808.74
HEIGHT OF MALE SHORES (IN)	AAA= 0
MALE SHORE STIFFNESS (KIPS/IN)	KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHS= 5825.13
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHK= 59223.08
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KSHP= 2212.17
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KKHP= 38434.86
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS)	QD1= 18098.07
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS)	QD2= 4817.6
RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS)	QD3= 2262.37
RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS)	QD4= 0
GRAVITATIONAL CONSTANT (IN/SEC^2)	GRAV= 386.09

SIDE BLOCK WIDTH (IN)	SBW= 42
KEEL BLOCK WIDTH (IN)	KBW= 48
SIDE BLOCK HEIGHT (IN)	SBH= 74
KEEL BLOCK HEIGHT (IN)	KBH= 60
BLOCK ON BLOCK FRICTION COEFFICIENT	U1= .43
HULL ON BLOCK FRICTION COEFFICIENT	U2= .53
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)	BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT	SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT	KCPL= .45
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2)	SAREA= 8352
TOTAL KEEL PIER CONTACT AREA (IN^2)	KAREA= 55440
PERCENT CRITICAL DAMPING	ZETA= .05
HULL NUMBER (XXXX)	HULL= 616
SYSTEM NUMBER (XXX)	NSYS= 1
CAP ANGLE (RAD)	BETA= .377

16369.9 193.0 2410451 10113.39 4025.64 46808.74 0.0 0.0  
 5825.13 59223.08 2212.17 38434.86 18098.07 4817.60 2262.37 386.09  
 42.00 48.00 74.00 60.00 0.43 0.53  
 144.00 0.70 0.45 8352.0 55440.0 0.050  
 616 1 0.377 0.00 46808.74

LAFAYETTE SSBN 616  
 NO ISOLATOR ALL BILINEAR  
 8 SPACING COMPOSITE  
 NO WALE SHORES  
 5 % DAMPING  
 NO SPECIFIC LOCATION  
 845-2006640  
 SIKHORIG.WK1 & SISHORIG.WK1  
 SIOBILN.DAT 1839 4 MAR 88



\*\*\*\* System 1 \*\*\*\*

\*\* Hull 616 \*\*

\* Ship Parameters \*

Weight	Moment of Inertia	K.G.
16369.9 kips	2410451.0 kips-in-sec <sup>2</sup>	193.0 ins

\* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
74.0 ins	42.0 ins	60.0 ins	48.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
144.0 ins	.0 ins	.0 kips/in	.377 rad
1Side Side Pier Contact Area	Total Keel Pier Contact Area	kkhp	
8352.0 in <sup>2</sup>	55440.0 in <sup>2</sup>	38434.9 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kshp	kvsp
.430	.530	2212.2 kips/in	4025.6 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	kvkp	
.700 kips/in <sup>2</sup>	.450 kips/in <sup>2</sup>	46808.7 kips/in	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness		
10113.4 kips/in	5825.1 kips/in		
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness		
46808.7 kips/in	59223.1 kips/in		
QD1	QD2	QD3	QD4
18098.1 kips	4817.6 kips	2262.4 kips	.0 kips

\* System Parameters and Inputs \*

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is

Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio	Data Time Increment
1.000	.010 sec

Gravitational Constant	% System Damping
386.09 in/sec <sup>2</sup>	5.00 %

# Mass Matrix

42.3992	.0000	8183.0420
.0000	42.3992	.0000
8183.0420	.0000	2410451.0000

# Damping Matrix

118.1018	.0000	5027.6454
.0000	168.5898	.0000
5027.6454	.0000	1549181.3597

# Stiffness Matrix

70873.3400	.0000	163103.6400
.0000	67035.5200	.0000
163103.6400	.0000	99931610.6070

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	6.425 rad/sec	69.650 rad/sec	39.763 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	6.416 rad/sec	69.563 rad/sec	39.713 rad/sec

For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.243397			11.22
Maximum Y		-.202029		8.01
Maximum Rotation			.048797	14.44
Side block sliding	-.103557	.033213	-.021226	6.24
Keel block sliding	-.095723	.021787	-.021704	6.23
Side block overturning	.082442	-.061166	.011885	5.61
Keel block overturning	.020383	.052877	.001717	4.71
Side block liftoff	-.007883	-.103857	-.003915	4.96
Side block crushing	-.009432	.021336	.009388	5.46

For Earthquake Acceleration of 90.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-0.246421			16.51
Maximum Y		-0.181860		8.01
Maximum Rotation			-0.049806	13.83
Side block sliding	.000484	-.055408	.002296	5.77
Keel block sliding	-.087291	.019017	-.019629	6.23
Side block overturning	.000484	-.055408	.002296	5.77
Keel block overturning	-.031319	-.030563	.001947	4.75
Side block liftoff	-.002232	-.081113	-.003868	4.97
Side block crushing	-.011740	-.012852	.009220	5.48

For Earthquake Acceleration of 80.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-0.250337			16.51
Maximum Y		-0.161793		8.01
Maximum Rotation			.049040	19.75
Side block sliding	.000027	-.051407	.001472	5.77
Keel block sliding	-.088423	.009133	-.017334	6.22
Side block overturning	.000027	-.051407	.001472	5.77
Keel block overturning	-.021642	.058728	-.005154	5.03
Side block liftoff	.001236	-.051243	-.003723	4.98
Side block crushing	.008197	-.014721	.008773	5.50

For Earthquake Acceleration of 70.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-0.248603			13.79
Maximum Y		-0.145349		8.01
Maximum Rotation			.049499	14.38
Side block sliding	-.026676	.040248	-.009791	6.28
Keel block sliding	-.083862	.039448	-.019523	7.37
Side block overturning	-.018619	.034936	-.011260	6.26
Keel block overturning	-.029241	-.004233	.007959	5.54
Side block liftoff	-.000110	-.023437	-.003463	4.99
Side block crushing	-.011305	-.039360	-.008468	5.92

For Earthquake Acceleration of 60.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.252173			13.78
Maximum Y		-.116732		8.00
Maximum Rotation			.049920	19.65
Side block sliding	-.003131	.021628	-.004153	6.30
Keel block sliding	.061008	.097166	.017490	7.93
Side block overturning	-.036400	.021380	-.007884	6.24
Keel block overturning	.022516	.054039	.004804	5.42
Side block liftoff	-.003402	.000282	-.003089	5.00
Side block crushing	.001256	-.018646	-.008745	5.96

For Earthquake Acceleration of 50.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.246529			19.66
Maximum Y		-.094418		8.00
Maximum Rotation			.049232	19.61
Side block sliding	-.015797	.008866	-.002023	6.31
Keel block sliding	-.093131	-.025568	-.026015	8.50
Side block overturning	-.015797	.008866	-.002023	6.31
Keel block overturning	.029000	.008726	.004903	5.52
Side block liftoff	-.014161	.033488	-.003067	5.03
Side block crushing	-.000834	-.062532	.008307	6.50

For Earthquake Acceleration of 40.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.241724			19.55
Maximum Y		-.071379		8.00
Maximum Rotation			.046794	19.50
Side block sliding	.032752	.002736	.006452	7.96
Keel block sliding	.084762	.009522	.023788	9.05
Side block overturning	.008986	.014682	-.001517	7.34
Keel block overturning	.027507	.013162	.007261	6.60
Side block liftoff	-.004834	.006973	.002687	5.38
Side block crushing	.000491	-.013729	.009022	7.53

For Earthquake Acceleration of 30.00 % of the 1940 EL CENTRO

Maxiums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.031730			8.07
Maximum Y		-.040973		8.00
Maximum Rotation			.005341	7.51
Keel block overturning	-.028676	.012919	-.003477	8.06
Side block liftoff	-.009727	.017853	-.002363	5.84

For Earthquake Acceleration of 20.00 % of the 1940 EL CENTRO

Maxiums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.018083			7.97
Maximum Y		-.026897		8.00
Maximum Rotation			.003646	7.50
Side block liftoff	.002507	.019660	.002589	6.42

For Earthquake Acceleration of 10.00 % of the 1940 EL CENTRO

Maxiums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.008056			7.98
Maximum Y		-.013437		4.79
Maximum Rotation			.001623	7.45

No failures occurred.

For Earthquake Acceleration of 19.00 % of the 1940 EL CENTRO

Maxiums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.017166			7.97
Maximum Y		-.025552		8.00
Maximum Rotation			.003456	7.50
Side block liftoff	.002767	.020286	.002591	6.43

For Earthquake Acceleration of 18.00 % of the 1940 EL CENTRO

Maximues/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.015413			7.97
Maximum Y		-.024186		4.79
Maximum Rotation			.003294	7.49
Side block liftoff	.010977	-.002288	.002979	6.54

For Earthquake Acceleration of 17.00 % of the 1940 EL CENTRO

Maximues/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.014521			7.97
Maximum Y		-.022842		4.79
Maximum Rotation			.003091	7.49
Side block liftoff	-.002400	-.002636	-.002636	6.99

For Earthquake Acceleration of 16.00 % of the 1940 EL CENTRO

Maximues/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.013572			7.97
Maximum Y		-.021499		4.79
Maximum Rotation			.002858	7.49
Side block liftoff	-.003316	.016301	-.002449	7.90

For Earthquake Acceleration of 15.00 % of the 1940 EL CENTRO

Maximues/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.013488			7.53
Maximum Y		-.020155		4.79
Maximum Rotation			.002624	7.48

No failures occurred.

## APPENDIX 2

1. "V2READs" and "ACCELMOD" FORTRAN  
Program Listings Sample Vertical and Horizontal
2. "DATINNEW" and "MAKERUB" BASIC Program  
Listings

# "V2READS" and "ACCELMOD" FORTRAN Program Listings. . . . .

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15:25:26

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```

D Line# 1      7
1 c          *****
2 c          v2reads.for
3 c          *****
4 c          main program to read the Volume2 data.
5 c          n = # of accel., velocity and displ. data
6 c
7 c          common/xyaxis/ixaxis,iyaxis,ixy
8             integer cortil(1000),icor(100),cor(40)
9             real y(500),fcor(100)
10            open(2,file='acc.dat',status='old')
11            open(3,file='acc1.out',status='new')
12            open(4,file='acc2.out',status='new')
13            open(5,file='acc3.out',status='new')
14            do 10 j=1,3
J 15            read(2,11)cortil
16            read(2,12)icor
17            read(2,13)fcor
18            n=icor(53)
19 c          Read the acceleration data:
20            read(2,11)cor
21            goto (100,200,300),j
22 100        read(2,13)(y(i),i=1,n)
23            write(3,14)(y(i),i=1,n)
24            goto 400
25 200        read(2,13)(y(i),i=1,n)
26            write(4,14)(y(i),i=1,n)
27            goto 400
28 300        read(2,13)(y(i),i=1,n)
29            write(5,14)(y(i),i=1,n)
30 400        continue
31 c          Read the velocity data:
32            read(2,11)cor
33            read(2,13)(y(i),i=1,n)
34 c          Read the displacement data:
35            read(2,11)cor
36            read(2,13)(y(i),i=1,n)
37 c          Read the "end of file" mark
38            read(2,11)ief
39 11          format(40a2)
40 12          format(16i5)
41 13          format(8f10.3)
42 14          format(f10.3)
43 10          continue
44            end

```

Name	Type	Offset P Class
COR	INTEGER*4	24806
CORTIL	INTEGER*4	2
FCOR	REAL	24406
I	INTEGER*4	24974
ICOR	INTEGER*4	4002
IEF	INTEGER*4	24982
J	INTEGER*4	24966
N	INTEGER*4	24970
Y	REAL	4402



D Line# 1 7 Microsoft FORTRAN77 V3.20 02/84

```

1 c acceleration data modification program
2
3 real a(2006),b(2006)
4 integer n,i,j
5 character*40 fname
6
7 write(*,*) 'INPUT FILE YOU WISH TO MODIFY...'
8 read(*, '(a)') fname
9 write(*,*) 'INPUT NUMBER OF DATA POINTS IN INPUT FILE ...'
10 read(*,*) n
11 open(2,file=fname,status='old')
12 open(3,file='acc.mod',status='new')
13
14 do 10 j=1,n
1 15 read(2,*)a(j)
1 16 10 continue
17 14 format(f9.4)
18
19 b(1)=a(1)
20 do 20 i=1,1002
1 21 b(2*i)=(a(i)+a(i+1))/2
1 22 b(2*i+1)=a(i+1)
1 23 20 continue
24
25 do 30 j=1,2004
1 26 write(3,14)b(j)
1 27 30 continue
28 end

```

Name	Type	Offset	P	Class
A	REAL	2		
B	REAL	8026		
FNAME	CHAR*40	16050		
I	INTEGER*4	16162		
J	INTEGER*4	16094		
N	INTEGER*4	16090		

Name	Type	Size	Class
MAIN			PROGRAM

Pass One No Errors Detected  
28 Source Lines

**"DATINNEW" and "MAKERUB" BASIC  
Program Listings. . . . .**

```

10 SCREEN 0: WIDTH 80
20 CLS
30 F=0
40 D$="###.###"
50 '
60 PRINT "*****"
70 '
80 PRINT:PRINT "          ****SHIP DRYDOCK BLOCKING SYSTEM****"
90 PRINT:PRINT "          **ACCELERATION DATA FILE CREATION PROGRAM**"
100 PRINT:PRINT "          **FOR BILINEAR 3DOF QUAKE RESPONSE PROGRAM**"
110 '
120 PRINT "*****"
130 '
140 '
150 INPUT " INPUT NAME OF ACCELERATION FILE YOU WISH TO MODIFY: ",ACOLD$
160 INPUT " HOW MANY DATA ENTRIES ARE IN THE INPUT DATA FILE? ",N
170 INPUT " HOW MANY DATA ENTRIES DO YOU WANT IN THE OUTPUT FILE? ",M
180 DIM AD(3000)
190 DIM AC(3000)
200 INPUT " WHAT PERCENT OF THE ORIGINAL ACCEL. DO YOU WANT ? (.XX) ",PP
210 INPUT " INPUT NAME OF OUTPUT ACCELERATION FILE: ",ACNEW$
220 INPUT " DO YOU WANT OUTPUT IN INCHES/SEC^2 ??? (Y/N) ";A$
230 IF A$="Y" OR A$="y" THEN F=1
240 INPUT " DO YOU WANT TO ADD LABELS TO THIS DATA FILE? (Y/N) ";B$
250 IF B$<>"Y" AND B$<>"y" THEN 300
260 FF=1
270 INPUT " INPUT THE NAME OF THE EARTHQUAKE: ";Q$
280 INPUT " INPUT THE ACCELERATION COMPONENT NAME: ";C$
290 INPUT " INPUT THE ACCELERATION DATA TIME STEP: (SEC) ";DTAU
300 OPEN ACOLD$ FOR INPUT AS #1
310 Z=1
320 GG=0
330 FOR I=1 TO N
340 INPUT #1,AD$
350 IF VAL(AD$)=0 AND I=1 THEN GG=1
360 IF GG=1 AND I=3 THEN 420
370 IF VAL(AD$)=0 THEN GOTO 420
380 AB=VAL(AD$)
390 IF AB=-9999 THEN 430
400 IF F=1 THEN AC(Z)=AB/2.54 ELSE AC(Z)=AB
410 Z=Z+1
420 NEXT I
430 CLOSE #1
440 OPEN ACNEW$ FOR OUTPUT AS #1
450 IF FF<>1 THEN 490
460 PRINT#1,Q$
470 PRINT#1,C$
480 PRINT#1, USING D$;DTAU
490 FOR I=1 TO M
500 PRINT#1, USING D$;AC(I)*PP
510 NEXT I
520 CLOSE #1
530 END

```

[illegible]

```

650 INPUT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN) " KVK="";KVK
660 INPUT " KEEL PIER VERTICAL PLAS STIFFNESS(KIPS/IN) " KVKP="";KVKP
670 INPUT " HEIGHT OF WALE SHORES (IN) " AAA="";AAA
680 INPUT " WALE SHORE STIFFNESS (KIPS/IN) " KS="";KS
690 INPUT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN) " KHS="";KHS
700 INPUT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN) " KHK="";KHK
710 INPUT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) " KSHP="";KSHP
720 INPUT " KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) " KKHP="";KKHP
730 INPUT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS) " QD1="";QD1
740 INPUT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS) " QD2="";QD2
750 INPUT " RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS) " QD3="";QD3
760 INPUT " RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS) " QD4="";QD4
770 INPUT " SIDE BLOCK WIDTH (IN) " SBW="";SBW
780 INPUT " KEEL BLOCK WIDTH (IN) " KBW="";KBW
790 INPUT " SIDE BLOCK HEIGHT (IN) " SBH="";SBH
800 INPUT " KEEL BLOCK HEIGHT (IN) " KBH="";KBH
810 INPUT " BLOCK ON BLOCK FRICTION COEFFICIENT " U1="";U1
820 INPUT " HULL ON BLOCK FRICTION COEFFICIENT " U2="";U2
830 INPUT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN) " BR="";BR
840 INPUT " SIDE PIER CAP PROPORTIONAL LIMIT " SCPL="";SCPL
850 INPUT " KEEL PIER CAP PROPORTIONAL LIMIT " KCPL="";KCPL
860 INPUT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) " SAREA="";SAREA
870 INPUT " TOTAL KEEL PIER CONTACT AREA (IN^2) " KAREA="";KAREA
880 INPUT " PERCENT CRITICAL DAMPING " ZETA="";ZETA
890 INPUT " HULL NUMBER (XXXX) " HULL="";HULL
900 INPUT " SYSTEM NUMBER (XXX) " NSYS="";NSYS
910 INPUT " CAP ANGLE (RAD) " BETA="";BETA
920 PRINT:PRINT
930 INPUT " ARE THE ABOVE VALUES CORRECT Y/N";YN$
940 IF YN$="N" THEN GOTO 270
950 CLS :PRINT
960 PRINT:PRINT
970 PRINT " SHIP/SYSTEM DATA FILE INPUT COMPLETE "
980 RETURN
990 '*****
1000 '
1010 CLS: 'SUBROUTINE "PRINT DATA"
1020 PRINT:PRINT " ***SHIP/SUB DRYDOCK BLOCKING SYSTEM*** DATA FILE: ";F4$
1030 PRINT:PRINT " ***INPUT FILE DATA***"
1040 PRINT:PRINT
1050 PRINT " SHIP NAME: ";SHIP$
1060 PRINT " DISCRPTION OF ISOLATORS IF USED: ";ISO$
1070 PRINT " DISCRPTION OF BUILDUP: ";BUILD$
1080 PRINT " DISCRPTION OF WALE SHORES USED: ";WALE$
1090 PRINT " DISCRPTION OF DAMPING: ";DAMP$
1100 PRINT " LOCATION OF DRYDOCK BEING STUDIED: ";DOCK$
1110 PRINT " NAVSEA DOCKING DRAWING NUMBER: ";SEA$
1120 PRINT " REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: ";STIF$
1130 PRINT " MISC. COMMENTS: ";COMM$
1140 PRINT
1150 PRINT
1160 PRINT " PRESS ANY KEY TO CONTINUE... "
1170 F$=INKEY$:IF F$="" THEN 1170
1180 CLS:PRINT
1190 '
1200 PRINT " SHIP WEIGHT (KIPS) " W="";W
1210 PRINT " HEIGHT OF KG (IN) " H="";H
1220 PRINT " MOMENT OF INERTIA (KIPS*IN*SEC^2) " Ik="";IK
1230 PRINT " SIDE PIER VERTICAL STIFFNESS (KIPS/IN) " Kvs="";KVS
1240 PRINT " SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN) " Kvsp="";KVSP
1250 PRINT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN) " KVK="";KVK
1260 PRINT " KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN) " KVKP="";KVKP
1270 PRINT " HEIGHT OF WALE SHORES (IN) " AAA="";AAA
1280 PRINT " WALE SHORE STIFFNESS (KIPS/IN) " KS="";KS
1290 PRINT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN) " KHS="";KHS
1300 PRINT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN) " KHK="";KHK
1310 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) " KSHP="";KSHP

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1310 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHF=";KSHF
1320 PRINT " KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KKHP=";KKHP
1330 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS) QD1=";QD1
1340 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS) QD2=";QD2
1350 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS) QD3=";QD3
1360 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS) QD4=";QD4
1370 PRINT " GRAVITATIONAL CONSTANT (IN/SEC^2) GRAV=";GRAV
1380 PRINT:PRINT " PRESS ANY KEY TO CONTINUE... "
1390 F$=INKEY$:IF F$="" THEN 1390
1400 CLS:PRINT
1410 '
1420 PRINT " SIDE BLOCK WIDTH (IN) SBW=";SBW
1430 PRINT " KEEL BLOCK WIDTH (IN) KBW=";KBW
1440 PRINT " SIDE BLOCK HEIGHT (IN) SBH=";SBH
1450 PRINT " KEEL BLOCK HEIGHT (IN) KBH=";KBH
1460 PRINT " BLOCK ON BLOCK FRICTION COEFFICIENT U1=";U1
1470 PRINT " HULL ON BLOCK FRICTION COEFFICIENT U2=";U2
1480 PRINT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN) BR=";BR
1490 PRINT " SIDE PIER CAP PROPORTIONAL LIMIT SCPL=";SCPL
1500 PRINT " KEEL PIER CAP PROPORTIONAL LIMIT KCPL=";KCPL
1510 PRINT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA=";SAREA
1520 PRINT " TOTAL KEEL PIER CONTACT AREA (IN^2) KAREA=";KAREA
1530 PRINT " PERCENT CRITICAL DAMPING ZETA=";ZETA
1540 PRINT " HULL NUMBER (XXXX) HULL=";HULL
1550 PRINT " SYSTEM NUMBER (XXX) NSYS=";NSYS
1560 PRINT " CAP ANGLE (RAD) BETA=";BETA
1570 PRINT:PRINT " PRESS ANY KEY TO CONTINUE... "
1580 F$=INKEY$:IF F$="" THEN 1580
1590 RETURN
1600 '*****
1610 '
1620 'SUBROUTINE "STORE DATA"
1630 IF NN<>2 THEN 1670
1640 CLS:PRINT
1650 INPUT " INPUT THE NAME OF THE MODIFIED DATA FILE: ",MD$
1660 F4$=ABC$+MD$
1670 OPEN F4$ FOR OUTPUT AS #1
1680 PRINT#1,USING A$;W;H;IK;KVS;KVSP;KVK;AAA;KS
1690 PRINT#1,USING B$;KHS;KHK;KSHP;KKHP;QD1;QD2;QD3;GRAV
1700 PRINT#1,USING C$;SBW;KBW;SBH;KBH;U1;U2
1710 PRINT#1,USING D$;BR;SCPL;KCPL;SAREA;KAREA;ZETA
1720 PRINT#1,USING E$;HULL;NSYS;BETA;QD4;KVKP
1730 PRINT#1," "
1740 PRINT#1," "
1750 PRINT#1," "
1760 PRINT#1," "
1770 PRINT#1," "
1780 PRINT#1,SHIP$
1790 PRINT#1,ISO$
1800 PRINT#1,BUILD$
1810 PRINT#1,WALES$
1820 PRINT#1,DAMP$
1830 PRINT#1,DOCK$
1840 PRINT#1,SEA$
1850 PRINT#1,STIF$
1860 PRINT#1,COMMS$
1870 '
1880 CLOSE #1
1890 RETURN
1900 '
1910 '*****
1920 '
1930 CLS: 'SUBROUTINE "RECALL DATA"
1940 PRINT "WAIT!!!! INPUTING PREVIOUS DATA FILE ----- "
1950 OPEN F4$ FOR INPUT AS #1
1960 INPUT#1,W,H,IK,KVS,KVSP,KVK,AAA,KS
1970 INPUT#1,KHS,KHK,KSHP,KKHP,QD1,QD2,QD3,GRAV

```

```

1980 INPUT#1, SBW, KBW, SBH, KBH, U1, U2
1990 INPUT#1, BR, SCPL, KCPL, SAREA, KAREA, ZETA
2000 INPUT#1, HULL, NSYS, BETA, QD4, KVKP
2010 INPUT#1, NULL$
2020 INPUT#1, NULL$
2030 INPUT#1, NULL$
2040 INPUT#1, NULL$
2050 INPUT#1, NULL$
2060 INPUT#1, SHIP$
2070 INPUT#1, ISO$
2080 INPUT#1, BUILD$
2090 INPUT#1, WALES$
2100 INPUT#1, DAMP$
2110 INPUT#1, DOCK$
2120 INPUT#1, SEAS$
2130 INPUT#1, STIF$
2140 INPUT#1, COMMS$
2150 CLOSE #1
2160 RETURN
2170 '
2180 '*****
2190 CLS: 'SUBROUTINE "MODIFY DATA"
2200 PRINT " SHIP WEIGHT (KIPS) W="; W
2210 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* W="; I$; IF I$<>" THEN W=VAL(I$)
2220 PRINT " HEIGHT OF KG (IN) H="; H
2230 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* H="; Q$; IF Q$<>" THEN H=VAL(Q$)
2240 PRINT " MOMENT OF INERTIA (KIPS*IN*SEC^2) Ik="; IK
2250 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Ik="; Q$; IF Q$<>" THEN IK=VAL(Q$)
2260 PRINT " SIDE PIER VERTICAL STIFFNESS (KIPS/IN) Kvs="; KVS
2270 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvs="; Q$; IF Q$<>" THEN KVS=VAL(Q$)
2280 PRINT " SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN) Kvsp="; KVSP
2290 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvsp="; Q$; IF Q$<>" THEN KVSP=VAL(Q$)
2300 PRINT " KEEL PIER VERTICAL STIFFNESS (KIPS/IN) KVK="; KVK
2310 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvk="; Q$; IF Q$<>" THEN KVK=VAL(Q$)
2320 PRINT " KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN) KVKP="; KVKP
2330 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Kvkp="; Q$; IF Q$<>" THEN KVKP=VAL(Q$)
2340 PRINT " HEIGHT OF WALE SHORES (IN) AAA="; AAA
2350 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* AAA="; Q$; IF Q$<>" THEN AAA=VAL(Q$)
2360 PRINT " WALE SHORE STIFFNESS (KIPS/IN) KS="; KS
2370 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KS="; Q$; IF Q$<>" THEN KS=VAL(Q$)
2380 PRINT " SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN) KHS="; KHS
2390 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* Khs="; Q$; IF Q$<>" THEN KHS=VAL(Q$)
2400 PRINT " KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN) KHK="; KHK
2410 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KHK="; Q$; IF Q$<>" THEN KHK=VAL(Q$)
2420 PRINT " SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN) KSHP="; KSHP
2430 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KSHP="; Q$; IF Q$<>" THEN KSHP=VAL(Q$)
2440 PRINT " KEEL PIER HORIZONTAL PLATIC STIFFNESS(KIPS/IN) KKHP="; KKHP
2450 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KKHP="; Q$; IF Q$<>" THEN KKHP=VAL(Q$)
2460 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS) QD1="; QD1
2470 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* QD1="; Q$; IF Q$<>" THEN QD1=VAL(Q$)
2480 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS) QD2="; QD2
2490 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* QD2="; Q$; IF Q$<>" THEN QD2=VAL(Q$)
2500 PRINT " RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS) QD3="; QD3
2510 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* QD3="; Q$; IF Q$<>" THEN QD3=VAL(Q$)
2520 PRINT " RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS) QD4="; QD4
2530 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* QD4="; Q$; IF Q$<>" THEN QD4=VAL(Q$)
2540 PRINT " GRAVITATIONAL CONSTANT (IN/SEC^2) GRAV="; GRAV
2550 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* GRAV="; Q$; IF Q$<>" THEN GRAV=VAL(Q$)

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2560 PRINT " SIDE BLOCK WIDTH (IN) SBW=";SBW
2570 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SBW=";Q$:IF Q$<>""THEN SBW=VAL(Q$)
2580 PRINT " KEEL BLOCK WIDTH (IN) KBW=";KBW
2590 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KBW=";Q$:IF Q$<>""THEN KBW=VAL(Q$)
2600 PRINT " SIDE BLOCK HEIGHT (IN) SBH=";SBH
2610 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SBH=";Q$:IF Q$<>""THEN SBH=VAL(Q$)
2620 PRINT " KEEL BLOCK HEIGHT (IN) KBH=";KBH
2630 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KBH=";Q$:IF Q$<>""THEN KBH=VAL(Q$)
2640 PRINT " BLOCK ON BLOCK FRICTION COEFFICIENT U1=";U1
2650 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* U1=";Q$:IF Q$<>""THEN U1=VAL(Q$)
2660 PRINT " HULL ON BLOCK FRICTION COEFFICIENT U2=";U2
2670 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* U2=";Q$:IF Q$<>""THEN U2=VAL(Q$)
2680 PRINT " SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN) BR=";BR
2690 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* BR=";Q$:IF Q$<>""THEN BR=VAL(Q$)
2700 PRINT " SIDE PIER CAP PROPORTIONAL LIMIT SCPL=";SCPL
2710 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SCPL=";Q$:IF Q$<>""THEN SCPL=VAL(Q$)
2720 PRINT " KEEL PIER CAP PROPORTIONAL LIMIT KCPL=";KCPL
2730 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KCPL=";Q$:IF Q$<>""THEN KCPL=VAL(Q$)
2740 PRINT " TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2) SAREA=";SAREA
2750 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SAREA=";Q$:IF Q$<>""THEN SAREA=VAL(Q$)
2760 PRINT " TOTAL KEEL PIER CONTACT AREA (IN^2) KAREA=";KAREA
2770 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* KAREA=";Q$:IF Q$<>""THEN KAREA=VAL(Q$)
2780 PRINT " PERCENT CRITICAL DAMPING ZETA=";ZETA
2790 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* ZETA=";Q$:IF Q$<>""THEN ZETA=VAL(Q$)
2800 PRINT " HULL NUMBER (XXXX) HULL=";HULL
2810 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* HULL=";Q$:IF Q$<>""THEN HULL=VAL(Q$)
2820 PRINT " SYSTEM NUMBER (XXX) NSYS=";NSYS
2830 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* NSYS=";Q$:IF Q$<>""THEN NSYS=VAL(Q$)
2840 PRINT " CAP ANGLE (RAD) BETA=";BETA
2850 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* BETA=";Q$:IF Q$<>""THEN BETA=VAL(Q$)
2860 PRINT " SHIP NAME: ";SHIP$
2870 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SHIP$=";Q$:IF Q$<>""THEN SHIP$=Q$
2880 PRINT " DISCRIPTION OF ISOLATORS IF USED: ";ISO$
2890 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* ISO$=";Q$:IF Q$<>""THEN ISO$=Q$
2900 PRINT " DISCRIPTION OF BUILDUP: ";BUILD$
2910 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* BUILD$=";Q$:IF Q$<>""THEN BUILD$=Q$
2920 PRINT " DISCRIPTION OF WALE SHORES USED: ";WALE$
2930 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* WALE$=";Q$:IF Q$<>""THEN WALE$=Q$
2940 PRINT " DISCRIPTION OF DAMPING: ";DAMP$
2950 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* DAMP$=";Q$:IF Q$<>""THEN DAMP$=Q$
2960 PRINT " LOCATION OF DRYDOCK BEING STUDIED: ";DOCK$
2970 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* DOCK$=";Q$:IF Q$<>""THEN DOCK$=Q$
2980 PRINT " NAVSEA DOCKING DRAWING NUMBER: ";SEA$
2990 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* SEA$=";Q$:IF Q$<>""THEN SEA$=Q$
3000 PRINT " REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: ";STIF$
3010 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* STIF$=";Q$:IF Q$<>""THEN STIF$=Q$
3020 PRINT " MISC. COMMENTS: ";COMMS$
3030 INPUT "NEW VALUE *NO CHANGE PRESS ENTER* COMMS$=";Q$:IF Q$<>""THEN COMMS$=Q$
3040 RETURN
3050
3060 '*****

```

### APPENDIX 3

1. Typical Accelerogram Header
2. Layout Sheet for *USS Leahy*  
Long Beach Dry Dock # 3
3. *Leahy* Horizontal and Vertical  
Stiffness Spreadsheets
4. System 1-11 and *USS Leahy*  
Stiffness Table
5. *Leahy* XEL, QD, KU, and KD Values  
for Bilinear Douglas Fir Caps
6. Rotational Moment of Inertia  
Calculation for *USS Leahy*
7. "3DOFRUB" *USS Leahy* Input Data File
8. *Leahy* Cap Angle Regression Analysis
9. "3DOFRUB" *USS Leahy* Output File



# Typical Accelerogram Header

CORRECTED ACCELEROGRAM 1111200 87.101.0 COMP VERT FILE 0 CORRESPONDING TO  
 FILE 0 OF UNCORRECTED ACCELEROGRAM DATA OF VOLUME 1:  
 WHITTIER EARTHQUAKE 19  
 OCT 01, 1987 -1442 GMT 22  
 1111200 87.101.0 N 18  
 STATION DD2L 0001 73 45 14N 118 13 48W 39  
 DD2 LENS 9  
 COMP VERT 9  
 WHITTIER EARTHQUAKE OCT 01, 1987 -1442 GMT 44  
 EPICENTER - 34 03 29N 118 04 30W 35  
 INSTR PERIOD = .037 SEC DAMPING = .590 SENSITIVITY = 1.78 CM/G 69  
 NO. OF POINTS = 3250 DURATION = 16.354 SEC 50  
 UNITS ARE SEC AND G/10 22  
 RMS ACCLN. OF COMPLETE RECORD = .051 G/10 45  
 ACCELEROGRAM IS BAND-PASS FILTERED BETWEEN .300- .400 AND 25.00-27.00 CYC/SEC.  
 B19 INSTRUMENT AND BASELINE CORRECTED DATA  
 AT EQUALLY-SPACED INTERVALS OF .020 SEC.  
 PEAK ACCELERATION = -13.05000 CMS/SEC/SEC AT 2.620 SEC.  
 PEAK VELOCITY = -1.08100 CMS/SEC AT 11.640 SEC.  
 PEAK DISPLACEMENT = .17300 CMS AT 14.760 SEC.  
 INITIAL VELOCITY = -.0220 CMS/SEC; INITIAL DISPLACEMENT = -.0320 CMS  
 WHITTIER EARTHQUAKE OCT 01, 1987 -1442 GMT  
 MAGNITUDE = 5.9 EPICENTRAL DISTANCE = 36.74 KM M.M.I. = 0.  
 1111200 87.101.0 DD2 LENS COMP VERT

0	4	4	200	87	101	0	1	1	73	45	14	118	13	48	34
3	29	118	4	20	10	1	1987	1442	4	500	3250	19	9	44	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	3250	3250	819	4	10	10	1	0	44	43	10	10	2	410
5	164	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.037	.590	16.354	.051	.100	1.780	34.058	118.075								
33.754	118.220	36.736	5.900	.000	5.000	.000	.000								
.000	.000	.000	.000	.000	.000	.000	.000								
.000	.000	.000	.000	.000	.000	.000	.000								
.000	.000	.000	.000	.000	.000	.000	.000								
.000	.000	.000	.000	.000	.000	.000	.000								
.000	.000	1.000	98.067	.005	16.354	169.816	1.000								
1.000	27.000	2.000	16.360	.020	.400	.100	.000								
2.620	-13.050	11.640	-1.081	14.760	.173	-.022	.400								
25.000	.200	.200	-.032	11.640	-1.081	14.800	.170								

Layout Sheet for *USS Leahy*  
Long Beach Dry Dock # 3 . .

BUILD KEEL HEIGHT TO  
10'-6" (ON DECLIVITY)

*OK*  
*7-30-87*  
*8/1/87*

BUSHIPS 1948741 REV. 1

USS LEAHY CG-16 DRYDOCK NUMBER 3 ON CENTERLINE BOW SOUTH POSITION NUMBER 2  
LOA 532'-6 5/16" BEAM 54'-9"  
RUDDER 7'-9" TO 22'-3" FROM SRP ON CENTERLINE----- 30 3/4" BELOW BASE  
PROPS 31'-6" FROM SRP 10'-6" OFF CENTERLINE P/S----- 3'-3 7/8" BELOW BASE  
AFT KNUCKLE 103'-0" FROM SRP----- OMIT PIERS AFT  
CENTERLINE NUMBER 1 BILGE BLOCKS 178'-0" FROM SRP---- BATTENS AFT SIDE  
ROD METER 294'-11" FROM SRP 3'-3 1/2" TO PORT----- OMIT PIERS 2'-0" F&A  
FWD KNUCKLE 466'-6" FROM SRP----- OMIT PIERS FWD  
SONAR DOME 468'-10" TO 506'-4" FROM SRP----- 5'-5" BELOW BASE  
FWD PERPENDICULAR 513'-11" FROM STERN REFERENCE POINT

DOCKSIDES

AOA 581'-9"  
RUDDER 574'-0" TO 559'-6"  
PROPS 550'-3"  
AFT KNUCKLE 478'-9"  
C/L NO. 1 BILGE BLOCKS 403'-9"  
ROD METER 286'-10"  
FWD KNUCKLE 115'-3"  
SONAR DOME 112'-11" TO 75'-5"  
FWD PERPENDICULAR 67'-10"  
FOA 49'-2 11/16"

KEEL RISE

RISE	SRP	DOCK SIDE
0"	376'-6"	205'-3"
+3/16"	401'-6"	180'-3"
+9/16"	426'-6"	155'-3"
+1 1/2"	451'-6"	130'-3"
+1 9/16"	459'-0"	122'-9"
+1 9/16"	466'-6"	115'-3"

6/21/47  
 7-30-47  
 CM  
 R. H. H.

USS LEAHY CG-16

SIDE BLOCKS

NO.	B-HB	PORT 18"		STBD 18"		SAD ANGLE
		B-HT	C-HT	B-HT	C-HT	
1	13-3-5+	3-9-6	4-4-1	3-9-6	4-4-1	370
2	13-5-4	3-3-3	3-9-5	3-3-3	3-9-5	362
3	13-7-2	2-10-2	3-4-4	2-10-2	3-4-4	362
4	13-9-0	2-6-0	3-0-3	2-6-2	3-0-6	370
5	13-10-2+	2-3-1	2-9-3	2-3-3	2-9-7	362
6	13-11-3	2-0-6	2-7-2	2-1-0	2-7-5	370
7	14-0-1	1-11-7	2-6-4	2-0-0	2-6-5	362
8	11-8-0	1-3-1	1-8-2	1-3-3	1-8-4	362
9	11-7-6+	1-3-4	1-8-6	1-3-7	1-9-1	362
10	11-7-5	OMIT	OMIT	1-5-0	1-10-4	362
11	11-7-1	1-7-0	2-0-0	1-6-6	2-0-5	362
12	11-6-4	1-9-0	2-3-5	1-9-0	2-3-5	362
13	11-5-3	1-11-5	2-6-7	OMIT	OMIT	362
14	11-3-5+	2-3-1	2-11-2	2-3-1	2-11-3	362
15	11-1-1	2-6-6	3-4-2	2-7-1	3-4-4	362

27-Jan-88 **Leahy Horizontal and Vertical Stiffness Spreadsheets. . . .**

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS ORIGINAL PER DOCKING DRAWING

USS LEAHY PLASTIC  
THIS IS A KEEL SYSTEM FOR USS LEAHY CG-16 WITH 12 FT BUILDUP  
12 FOOT CENTERS

USS LEAHY  
KEEL BLOCK  
HORIZONTAL  
PLASTIC  
STIFFNESS

(1) 302 30 2 12 12 12

ELEMENT # 1 CONCRETE				
E1	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B1	H1	I1	L1
(IN)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
4000000	42	96	3096576	48

12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1
1344000000	32256000000	1032192000000	516096000000

RIGIDITY	TOP	SHEAR	ELEMENT
6Ir	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
(IN <sup>2</sup> )	(IN <sup>2</sup> )	(IN)	(IN)
2400000	4032	0.0000001033	0.0000049603

ELEMENT # 2 CONCRETE				
E2	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B2	H2	I2	L2
(IN)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
4000000	42	48	387072	66

12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2
64625093.914	2132628099.2	9383563636.4	46917818182

RIGIDITY	TOP	SHEAR	ELEMENT
6Ir	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
(IN <sup>2</sup> )	(IN <sup>2</sup> )	(IN)	(IN)
2400000	2016	0.0000002067	0.0000136409

ELEMENT # 3 OAK				
E3 (PSI)	DEPTH B3 (IN)	TRANSVERSE H3 (IN)	I3 (IN <sup>4</sup> )	HEIGHT L3 (IN)
335720	42	64	917504	30
12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3	
1.3690E+08	2.0535E+09	4.1070E+10	2.0535E+10	
RIGIDITY Glr (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	
23980	2688	0.0000135139	0.0004654176	

ELEMENT # 4 DOUGLAS FIR				
E4 (PSI)	DEPTH B4 (IN)	TRANSVERSE H4 (IN)	I4 (IN <sup>4</sup> )	HEIGHT L4 (IN)
45629	42	26	61516	6
12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4	
1.6619E+08	4.9058E+08	1.9943E+09	9.9715E+08	
RIGIDITY Glr (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	TOTAL SHEAR DEFLECTION (IN)
3474	764.4	0.0003766275	0.002239765	2.7438E-03

STIFFNESS MATRIX

F/ N	D														
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
01	1.340E+09	3.225E+10	-1.340E+09	3.225E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
02	3.225E+10	1.032E+12	-3.225E+10	5.161E+11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
03	-1.340E+09	-3.225E+10	1.408E+09	-3.012E+10	-6.465E+07	2.132E+07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
04	3.225E+10	5.161E+11	-3.012E+10	1.126E+12	-2.132E+09	4.691E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
05	0.000E+00	0.000E+00	-6.465E+07	-2.132E+09	2.015E+08	-7.913E+07	-1.365E+08	2.053E+09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
06	0.000E+00	0.000E+00	2.132E+09	4.691E+10	-7.913E+07	1.3491E+11	-2.053E+09	2.053E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.365E+08	-2.053E+09	3.030E+08	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09
08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.053E+09	2.053E+10	-1.554E+09	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10
09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09
10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10
11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09
12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10
13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09
14	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10	4.304E+10
15	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09	-1.554E+09

# KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1(L1+L2+L3+L4) = -150000 IN#LBS  
Q2 = Q3 = Q4 = Q5 = 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

60

## SOLVED UNKNOWN:

q2= 0.000124628 in  
th2 0.000004883 rad  
q3 0.000157226 in  
th3 0.000034296 rad  
q4 0.0002980984 in  
th4 0.000054799 rad  
q5 0.0003550162 in  
th5 0.00011492 rad  
K (BEND HORIZ) FOR 1 KEEL BLOCK = 3354.24 KIPS/IN

K (BEND HORIZ) ALL KEEL BLOCKS = 201275823.1 lbs/in 201275.8231 KIPS/IN

## MATRIX CHECK:

Q1 = -1000.0000  
M1 = -150000.0000  
Q2 = 0.0000  
M2 = 0.0000  
Q3 = 0.0000  
M3 = 0.0000  
Q4 = -0.0000  
M4 = -0.0000  
Q5 = 1000.0000  
M5 = 0.0000

## TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION: USS LEAHY CG-16 PLASTIC

Khk (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk = 327.71 KIPS/IN (PER KEEL)  
Khk = 19362.33 KIPS/IN (ENTIRE KEEL BLOCK SYSTEM)

27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS ORIGINAL PER DOCKING DRAWING

USS LEAHY PLASTIC  
THIS IS A SIDE BLOCK SYSTEM FOR USS LEAHY CG-16 WITH 12.5 FT BUILDUP  
12 FOOT CENTERS

USS LEAHY  
SIDE BLOCK  
HOR BLOCK  
PLASTIC  
12.5 FT  
305112 KIP/IN

ELEMENT # 1 CONCRETE				
E1	DEPTH	TRANSVERSE	I1	HEIGHT
(PSI)	B1	M1	(IN <sup>4</sup> )	L1
	(IN)	(IN)		(IN)
4000000	96	168	37933056	48

12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1
16464000000	395136000000	12644352000000	6322176000000

RIGIDITY	TOP	SHEAR	ELEMENT
G1r	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
2400000	16128	0.0000000258	0.0000012401

ELEMENT # 2 CONCRETE				
E2	DEPTH	TRANSVERSE	I2	HEIGHT
(PSI)	B2	M2	(IN <sup>4</sup> )	L2
	(IN)	(IN)		(IN)
4000000	48	100	4000000	66

12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2
667835378.58	22038567493	%%%%%%97	484848484848

RIGIDITY	TOP	SHEAR	ELEMENT
G1r	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
2400000	3360	0.000000124	0.0000081845



ELEMENT # 3 OAK		DEPTH		TRANSVERSE		HEIGHT	
E3		B3		H3		L3	
(PSI)		(IN)		(IN)		(IN)	
335720		50		93		3351487.5	57

12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3
7.2907E+07	2.0779E+09	7.8959E+10	3.9479E+10
RIGIDITY	TOP	SHEAR	ELEMENT
GIr	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
(IN*2)			(IN)
23980	4650	0.000008968	0.0005111787

ELEMENT # 4 DOUGLAS FIR		DEPTH		TRANSVERSE		HEIGHT	
E4		B4		H4		L4	
(PSI)		(IN)		(IN)		(IN)	
48629		28		18		13608	6

12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4	
3.6764E+07	1.1029E+08	4.4116E+08	2.2058E+08	
RIGIDITY	TOP	SHEAR	ELEMENT	TOTAL
GIr	CONTACT	STRAIN	SHEAR	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION	DEFLECTION
	(IN^2)		(IN)	(IN)
3474	504	0.0005712184	0.0034273102	3.9479E-03

F/ M	STIFFNESS MATRIX															D
	q1	m1	q2	m2	q3	m3	q4	m4	q5	m5	q1	m1	q2	m2	q3	
q1	1.646E+10	3.951E+11	-1.646E+10	3.951E+11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q1
m1	3.951E+11	1.264E+13	-3.951E+11	6.322E+12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 m1
q2	-1.646E+10	-3.951E+11	1.713E+10	-3.731E+11	-6.678E+08	2.203E+10	4.848E+11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q2
m2	3.951E+11	6.322E+12	-3.731E+11	1.361E+13	-2.203E+10	7.407E+08	-1.996E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 m2
q3	0.000E+00	0.000E+00	-6.678E+08	-2.203E+10	7.407E+08	7.407E+08	-1.996E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q3
m3	0.000E+00	0.000E+00	2.203E+10	7.407E+08	-1.996E+10	1.048E+12	1.048E+12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 m3
q4	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-7.290E+07	-2.077E+09	-2.077E+09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q4
m4	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.077E+09	3.947E+10	3.947E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 m4
q5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q5
m5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 m5

KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1\*(L1+L2+L3+L4) = -177000 IN\*lbs  
Q2 = Q2 = Q3 = Q4 = Q5 = 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

14

SOLVED UNKNOWN:

q2 = 0.000012224 in  
th2 = 0.000000484 rad  
q3 = 0.000189822 in  
th3 = 0.000004444 rad  
q4 = 0.00010784 in  
th4 = 0.000002192 rad  
q5 = 0.000297964 in  
th5 = 0.00002993 rad  
K (BEND HORIZ) FOR 1 SIDE BLOCK = 9273000.8265 lbs/in  
K (BEND HORIZ) ALL SIDE BLOCKS = 129822011.571 lbs/in

-B1 -B2  
-2883.0278465 -202873.50847  
-3307.3464598 -137531.70582

-5206.3503209 -18860.324477

9273.0008265 KIPS/IN

129822.011571 KIPS/IN

MATRIX CHECK:

Q1 = -1000.0000  
M1 = -177000.0000  
Q2 = 0.0000  
M2 = 0.0000  
Q3 = -0.0000  
M3 = 0.0000  
Q4 = -0.0000  
M4 = -0.0000  
Q5 = 1000.0000  
M5 = -0.0000

TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:  
USS LEAHY PLASTIC

Khs (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khs = 239.37 KIPS/IN (PER BLOCK)  
Khs = 3351.12 KIPS/IN (ENTIRE SIDE BLOCK SYSTEM)

# KNOWN VALUES:

$Q1 = -1000 \text{ lbs}$   
 $M1 = Q1 \cdot (L1 + L2 + L3 + L4) = -177000 \text{ IN*LB}$   
 $Q2 = Q3 = Q4 = Q5 = 0$   
 $Q5 = 1000 \text{ lbs}$   
 $q1 = th1 = 0$

# OF SYSTEM BLOCKS =

14

## SOLVED UNKNOWN:

$q2 = 0.0000012224 \text{ in}$   
 $th2 = 0.0000000484 \text{ rad}$   
 $q3 = 0.000189822 \text{ in}$   
 $th3 = 0.000004444 \text{ rad}$   
 $q4 = 0.00010784 \text{ in}$   
 $th4 = 0.0000021922 \text{ rad}$   
 $q5 = 0.0002297964 \text{ in}$   
 $th5 = 0.000029393 \text{ rad}$   
 $K \text{ (BEND HORIZ) FOR 1 SIDE BLOCK} = 9273000.8265 \text{ lbs/in}$   
 $K \text{ (BEND HORIZ) ALL SIDE BLOCKS} = 129822011.571 \text{ lbs/in}$

$-B1$   
 $-2883.0278465$

$-B2$   
 $-202873.50847$

$-3307.3464598$

$-137531.70582$

$-3206.3503204$

$-18860.324477$

$9273.0008265 \text{ KIPS/IN}$

$129822.011571 \text{ KIPS/IN}$

## MATRIX CHECK:

$Q1 = -1000.0000$   
 $M1 = -177000.0000$   
 $Q2 = 0.0000$   
 $M2 = 0.0000$   
 $Q3 = -0.0000$   
 $M3 = 0.0000$   
 $Q4 = -0.0000$   
 $M4 = -0.0000$   
 $Q5 = 1000.0000$   
 $M5 = -0.0000$

## TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION: USS LEAMY PLASTIC

$K_{hs} \text{ (SIDE BLOCK HORIZONTAL STIFFNESS)} = P / (\text{BENDING DISPL} + \text{SHEAR DISPLACEMENT})$

$K_{hs} = 239.37 \text{ KIPS/IN}$  (PER BLOCK)

$K_{hs} = 3351.12 \text{ KIPS/IN}$  (ENTIRE SIDE BLOCK SYSTEM)

27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS

ORIGINAL PER DOCKING DRAWING

USS LEAHY ELASTIC

THIS IS A KEEL SYSTEM FOR USS LEAHY CG-16 WITH 12 FT BUILDUP  
12 FOOT CENTERS

USS LEAHY  
KEEL BLOCK  
HORIZONTAL  
ELASTIC  
STIFFNESS  
414-25242

ELEMENT # 1		CONCRETE			HEIGHT L1 (IN)
E1 (PSI)	DEPTH D1 (IN)	TRANSVERSE H1 (IN)		I1 (IN <sup>4</sup> )	
4000000	42	96		3096576	48

12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1
1344000000	32256000000	1032192000000	516096000000

RIGIDITY G1r (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)
2400000	4032	0.0000001033	0.0000049603

ELEMENT # 2		CONCRETE			HEIGHT L2 (IN)
E2 (PSI)	DEPTH D2 (IN)	TRANSVERSE H2 (IN)		I2 (IN <sup>4</sup> )	
4000000	42	48		387072	66

12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2
64625093.914	2132628099.2	93835636364	46917818132

RIGIDITY G1r (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)
2400000	2016	0.0000002067	0.0000136409

ELEMENT # 3 OAK		DEPTH	TRANSVERSE		HEIGHT
E3	B3	H3	I3	L3	
(PSI)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
335720	42	64	917504	30	

12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3
1.3690E+08	2.0535E+09	4.1070E+10	2.0535E+10

RIGIDITY	TOP	SHEAR	ELEMENT
GIr	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
23980	2688	0.0000155139	0.0004654176

ELEMENT # 4 DOUGLAS FIR		DEPTH	TRANSVERSE		HEIGHT
E4	B4	H4	I4	L3	
(PSI)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
175549	42	26	61516	6	

12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4
5.9995E+08	1.7998E+09	7.1994E+09	3.5997E+09

RIGIDITY	TOP	SHEAR	ELEMENT	TOTAL
GIr	CONTACT	STRAIN	SHEAR	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION	DEFLECTION
	(IN <sup>2</sup> )		(IN)	(IN)
12539	764.4	0.0001043299	0.0006239797	1.1100E-03

# STIFFNESS MATRIX

F/ M	D														
	q1	q2	q3	q4	q5	q6	q7	q8	q9	q10	q11	q12	q13	q14	q15
q1	1.3440E+09	3.2256E+10	-1.3440E+09	3.2256E+10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q2	3.2256E+10	1.0320E+12	-3.2256E+10	5.1610E+11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q3	-1.3440E+09	-3.2256E+10	1.4086E+09	-3.0123E+10	-6.4625E+07	2.1326E+09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q4	3.2256E+10	5.1610E+11	-3.0123E+10	1.1264E+12	-2.1326E+09	4.6918E+10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q5	0.0000E+00	0.0000E+00	-6.4625E+07	-2.1326E+09	2.0152E+08	-7.9132E+07	-1.3690E+08	2.0535E+09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q6	0.0000E+00	0.0000E+00	2.1326E+09	4.6918E+10	-7.9132E+07	1.3491E+11	-2.0535E+09	2.0535E+10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-1.3690E+08	-2.0535E+09	7.3655E+08	-2.5315E+08	-5.9994E+08	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.0535E+09	2.0535E+10	-2.5315E+08	4.8835E+10	-1.7998E+09	3.5995E+09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q9	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-5.9994E+08	-1.7998E+09	5.9994E+08	-1.7998E+09	3.5995E+09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
q10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.7998E+09	3.5995E+09	-1.7998E+09	-1.7998E+09	7.1993E+09	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

# KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1(L1+L2+L3+L4) = -150000 IN\*lbs  
Q2 = Q3 = Q4 = Q5 = 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

60

## SOLVED UNKNOWN:

q2 = 0.000124628 in  
th2 = 0.000004883 rad  
q3 = 0.000157226 in  
th3 = 0.000034296 rad  
q4 = 0.000298098 in  
th4 = 0.000054749 rad  
q5 = 0.000337615 in  
th5 = 0.000071417 rad  
K (BEND HORIZ) FOR 1 KEEL BLOCK = 3354597.0517 lbs/in  
K (BEND HORIZ) ALL KEEL BLOCKS = 20127562.11 lbs/in

-B1 -B2  
-2846.7317806 -174396.69421  
-29566.937031 -499717.35324  
-189697.222 -581946.11317

3354.5970517 KIPS/IN

20127.56211 KIPS/IN

## MATRIX CHECK:

Q1 = -1000.0000  
M1 = -150000.0000  
Q2 = 0.0000  
Q3 = 0.0000  
Q4 = -0.0000  
Q5 = 1000.0000  
Q6 = 0.0000

## TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION: USS LEAHY CG-16 ELASTIC

Khk (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk = 690.79 KIPS/IN (PER BLOCK)  
Khk = 41447.53 KIPS/IN (ENTIRE KEEL BLOCK SYSTEM)



27-Jan-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS

ORIGINAL PER DOCKING DRAWING

USS LEAHY ELASTIC

THIS IS A SIDE BLOCK SYSTEM FOR USS LEAHY CG-16 WITH 12.5 FT BUILDUP  
12 FOOT CENTERS

000 10-2-1  
SIDE BLOCK  
FOR 12.5 FT  
BUILDUP  
8600291-1/12

ELEMENT # 1 CONCRETE				
E1	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B1	M1	I1	L1
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
4000000	96	168	37933056	48

12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1
16464000000	395136000000	12644352000000	6322176000000

RIGIDITY	TOP	SHEAR	ELEMENT
6Ir	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
2400000	16128	0.0000000258	0.0000012401

ELEMENT # 2 CONCRETE				
E2	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B2	M2	I2	L2
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
4000000	48	100	4000000	66

12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2
667835378.58	22038567493	9696969697	4848484848

RIGIDITY	TOP	SHEAR	ELEMENT
6Ir	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)

ELEMENT # 3 OAK				
E3 (PSI)	DEPTH B3 (IN)	TRANSVERSE H3 (IN)	I3 (IN <sup>4</sup> )	HEIGHT L3 (IN)
335720	50	93	3351487.5	57
12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3	
7.2907E+07	2.0779E+09	7.8954E+10	3.9474E+11	
RIGIDITY Glr (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	
23980	4630	0.000008968	0.0005111787	

ELEMENT # 4 DOUGLAS FIR				
E4 (PSI)	DEPTH B4 (IN)	TRANSVERSE H4 (IN)	I4 (IN <sup>4</sup> )	HEIGHT L4 (IN)
175549	28	18	13608	6
12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4	
1.3271E+08	3.9814E+08	1.5926E+09	7.9629E+08	
RIGIDITY Glr (PSI)	TOP CONTACT AREA (IN <sup>2</sup> )	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	TOTAL SHEAR DEFLECTION (IN)
12539	504	0.0001582341	0.0009494048	1.4700E-03

STIFFNESS MATRIX

F/ H	D														
01	1.646E+10	3.951E+11	-1.646E+10	3.951E+11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q1
H1	3.951E+11	1.264E+13	-3.951E+11	6.322E+12	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 H1
02	-1.646E+10	-3.951E+11	1.713E+10	-3.731E+11	-6.678E+08	2.203E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q2
H2	3.951E+11	6.322E+12	-3.731E+11	1.361E+13	-2.203E+10	4.848E+11	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 H2
03	0.000E+00	0.000E+00	-6.678E+08	-2.203E+10	7.407E+08	-1.951E+10	-7.290E+07	2.077E+09	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 q3
H3	0.000E+00	0.000E+00	2.203E+10	4.848E+11	-1.951E+10	1.048E+12	-2.077E+09	3.947E+10	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00 H3
04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-7.290E+07	-2.077E+09	2.052E+08	-1.679E+09	-1.679E+09	-1.3271E+08	3.9814E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08 q4
H4	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.077E+09	3.947E+10	-1.679E+09	8.0531E+10	-3.9814E+08	1.3271E+08	-3.9814E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08 H4
05	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-1.3271E+08	-3.9814E+08	1.3271E+08	-3.9814E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08 q5
H5	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	3.9814E+08	7.9628E+08	-3.9814E+08	-3.9814E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08	7.9628E+08 H5

# KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1\*(L1+L2+L3+L4) = -177000 IN\*LB  
Q2 = Q3 = Q4 = Q5 = 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

14

## SOLVED UNKNOWN:

q2 = 0.000012224 in

th2 = 0.000000484 rad

q3 = 0.000189822 in

-B1 -B2  
-2883.0278465 -202873.50847

th3 = 0.000000444 rad

q4 = 0.00010784 in

-3307.3464598 -137531.70582

th4 = 0.000002192 rad

q5 = 0.0001511327 in

-16184.7430109 -52427.02096

th5 = 0.0000097271 rad

K (BEND HORIZ) FOR 1 SIDE BLOCK = 9273000.8265 lbs/in 9273.0008265 KIPS/IN

K (BEND HORIZ) ALL SIDE BLOCKS = 129822011.571 lbs/in 129822.011571 KIPS/IN

## MATRIX CHECK:

Q1 = -1000.0000

M1 = -177000.0000

Q2 = 0.0000

M2 = 0.0000

Q3 = -0.0000

M3 = 0.0000

Q4 = 0.0000

M4 = 0.0000

Q5 = 1000.0000

M5 = -0.0000

## TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION: USS LEAHY ELASTIC

Khs (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khs = 616.85 KIPS/IN (PER BLOCK)

Khs = 8635.89 KIPS/IN (ENTIRE SIDE BLOCK SYSTEM)

VERTICAL STIFFNESS CALCULATIONS FOR DRYDOCK BLOCKS

HULL TYPE 16 DOCKING PLAN # 194787417 REV 1

SYSTEM # USS LEAHY KEEL BLOCKS ORIGINAL PER DOCKING DRAWING

BLOCK SPA 12.00 FEET

VERTICAL STIFFNESS:

USS LEAHY  
KEEL BLOCK  
VERTICAL  
ELASTIC  
STIFFNESS

65590.62 KIPS/IN

LEVEL #	MATERIAL	E (PSI)	LENGTH (IN)	WIDTH (IN)	HEIGHT (IN)	K (KIPS/IN)	1/K	PIER TOTAL K (KIPS/IN)
			(DEPTH) (B)	(TRANSVERSE) (H)	(L)			
1	D.FIR	12539.19	42.00	26.00	6.00	2282.13	0.0004382	1093.18
2	OAK	23980.00	42.00	64.00	30.00	2148.61	0.0004654	
3	CONCRETE	4000000.00	42.00	48.00	66.00	122181.82	0.0000082	
4	CONCRETE	4000000.00	42.00	96.00	48.00	336000.00	0.0000030	
					150.00			
		1845.83			12.50			
					0 BLOCKS	60		TOTAL STIFF OF BLOCK SY (KIPS/IN)
								65590.62

# VERTICAL STIFFNESS CALCULATIONS

HULL TYPE 16 DOCKING PLAN # = 1948741 REV 1

SYSTEM # 1 ELASTIC SIDE BLOCKS ORIGINAL PER DOCKING DRAWING

BLOCK SPACING = 12.00 FEET

VERTICAL STIFFNESS:

LEVEL #	MATERIAL	E (PSI)	LENGTH (IN)	WIDTH (IN)	HEIGHT (IN)	K (KIPS/IN)	1/K	PIER TOTAL K (KIPS/IN)
			(DEPTH) (B)	(TRANSVERSE) (H)	(L)			
1	D.FIR	12539.19	28.00	18.00	6.00	1053.29	0.0009494	682.70
2	DAK	23980.00	50.00	93.00	57.00	1956.26	0.0005112	
3	CONCRETE	4000000.00	48.00	100.00	66.00	290909.09	0.0000034	
4	CONCRETE	4000000.00	96.00	168.00	48.00	1344000.00	0.0000007	
					177.00			
					177.00			
		850.00						
					BLOCKS	14		
								TOTAL STIFF OF BLOCK SY (KIPS/IN):

USS LEAHY  
SIDE BLOCK  
VERTICAL  
STIFFNESS  
ELASTIC  
9557.85 KIPS/IN

9557.85

USS LEAHY  
SIDE BLOCK  
VERTICAL  
PLASTIC  
STIFFNESS

# VERTICAL STIFFNESS CALCULATIONS

HULL TYPE 16 DOCKING PLAN # = 1948741 REV 1

SYSTEM # 1 PLASTIC SIDE BLOCKS ORIGINAL PER DOCKING DRAWING

BLOCK SPACING = 12.00 FEET

VERTICAL STIFFNESS:

LEVEL #	MATERIAL	E (PSI)	LENGTH (IN)	WIDTH (IN)	HEIGHT (IN)	K (KIPS/IN)	1/K	PIER TOTAL K (KIPS/IN)
			(DEPTH) (B)	(TRANSVERSE) (H)	(L)			
1	D.FIR	3473.50	28.00	18.00	6.00	291.00	0.0034364	2.0101
2	DAK	23980.00	42.00	64.00	57.00	1130.85	0.0008843	
3	CONCRETE	4000000.00	48.00	100.00	66.00	290909.09	0.0000034	
4	CONCRETE	4000000.00	96.00	168.00	48.00	1344000.00	0.0000007	
					177.00			
					177.00			
		850.00						
					BLOCKS	14		
								TOTAL STIFF OF BLOCK SY (KIPS/IN):

3243.91

# System 1-11 and USS Leahy Stiffness Table . . . .

TOTAL KEEL AND SIDE PIER STIFFNESS KIPS/IN  
BILINEAR SYSTEMS (1-11) PER BOXING DRAWINGS & USS LEAHY CS-16

SYSTEM	KWK	KVS	KVSP	KVK	KVSP	KVS	KSP
1	46808.74	10113.39	4025.64	59223.06	38439.86	5825.13	2212.17
2	46808.74	5231.06	2082.23	59223.06	38439.86	3013.00	1144.23
3	31919.89	6178.56	3211.52	28875.45	22849.71	4005.29	1897.66
4	31919.89	3195.81	1661.13	28875.45	22849.71	2097.56	981.55
5	46808.74	3195.81	1661.13	59223.06	38439.86	2097.56	981.55
6	82270.20	43011.07	22859.52	79683.44	53718.39	28797.14	13345.17
7	82270.20	28512.95	14762.94	79683.44	53718.39	19090.24	8946.80
8	82270.20	21747.17	11259.87	79683.44	53718.39	14560.35	6747.56
9	24375.19	8629.57	4045.53	22050.35	17448.87	3842.63	2409.13
10	19442.11	6808.09	3188.10	17587.78	13917.35	4625.36	1894.63
11	19442.11	5236.99	2432.39	17587.78	13917.35	3557.97	1454.33
LEAHY	65590.62	9557.85	3243.91	41447.53	19562.33	8635.89	3331.12

## Leahy XEL, QD, KU, and KD Values for Bilinear Douglas Fir Caps . .

ED VALUES:  
1 = KEEL HORIZONTAL STIFFNESS  
2 = SIDE BLOCK HORIZONTAL STIFFNESS  
3 = SIDE BLOCK VERTICAL STIFFNESS

SYSTEM	KEEL	CONT.	SHEAR	DE	KVK	KEL1	KU1-KD1	QD1	SP	CAP	SHEAR	DE	KVS	KEL2	KUP-KD2	QD2	CAPAREA	PROP	LIMI	KIPS/IN	(PSI)	KVS	YEL1	KU3-KD3	QD3
#	AREA	(IN <sup>2</sup> )	PRPD	LIMI	(KIPS/IN)	(IN)	(KIPS/IN)	(KIPS)	AREA	(IN <sup>2</sup> )	PRPD	LIMI	(KIPS/IN)	(IN)	(KIPS/IN)	(KIPS)	(IN <sup>2</sup> )	(IN <sup>2</sup> )	(PSI)	(KIPS/IN)	(PSI)	(IN)	(KIPS/IN)	(KIPS)	
1	59440.00		930.0	59223.1	0.8706	20788.22	18098.07	8332.00	930.0	5825.13	1.3334	3612.96	4817.602	1.3334	1868.77	2491.858	8332.00	450.0	10113.39	0.3716	6087.75	2562.366			
2	59440.00		930.0	59223.1	0.8706	20788.22	18098.07	4320.00	930.0	3013.00	1.3334	1868.77	2491.858	1.3334	1868.77	2491.858	4320.00	450.0	5231.06	0.3716	3148.83	1170.188			
3	59440.00		930.0	28875.5	1.7856	6025.74	10759.39	8332.00	930.0	4055.29	1.9154	2157.63	4132.140	1.9154	2157.63	4132.140	8332.00	450.0	6178.56	0.6083	2967.04	1804.841			
4	59440.00		930.0	28875.5	1.7856	6025.74	10759.39	5220.00	930.0	2097.56	2.3144	1116.01	2382.897	2.3144	1116.01	2382.897	5220.00	450.0	3195.81	0.7350	1534.68	1128.028			
5	59440.00		930.0	59223.1	0.8706	20788.22	18098.07	5220.00	930.0	2097.56	2.3144	1116.01	2382.897	2.3144	1116.01	2382.897	5220.00	450.0	3195.81	0.7350	1534.68	1128.028			
6	10884.00		930.0	79683.4	1.2706	27965.05	37990.45	57672.00	930.0	28797.14	1.8625	15851.97	28779.44	1.8625	7812.79	14531.50	57672.00	450.0	43011.07	0.6034	20741.55	12011.21			
7	10884.00		930.0	79683.4	1.2706	27965.05	37990.45	38232.00	930.0	19090.24	1.8625	10243.44	19078.50	1.8625	10243.44	19078.50	38232.00	450.0	28512.95	0.6034	13750.01	8256.604			
8	42336.00		930.0	22050.4	1.7856	6401.48	1216.272	9600.00	930.0	5842.63	1.5281	3433.46	5246.596	1.5281	3433.46	5246.596	9600.00	450.0	21747.17	0.6034	10487.3	6327.919			
9	37468.00		930.0	17587.8	1.7856	3670.23	6553.458	7488.00	930.0	4625.36	1.5056	2794.73	4117.349	1.5056	2794.73	4117.349	7488.00	450.0	6808.09	0.4949	3619.99	1791.479			
10	37468.00		930.0	17587.8	1.7856	3670.23	6553.458	5760.00	930.0	3557.97	1.5056	2103.44	3167.190	1.5056	2103.44	3167.190	5760.00	450.0	5236.99	0.4949	2784.6	1378.212			
11	60880.00		930.0	41447.5	1.3571	22065.2	29570.73	7056.00	930.0	8635.89	0.7959	5284.77	4015.693	0.7959	5284.77	4015.693	7056.00	450.0	9557.85	0.3322	6313.94	2097.545			
LEAHY																									

# Rotational Moment of Inertia Calculation for *USS Leahy* . .

## ROTATIONAL MOMENT OF INERTIA CALCULATOR ABOUT THE KEEL:

SHIP NAME: USS LEAHY CG-16

$$I_{\text{keel}} = I_{xx} + T^2 \cdot W/g$$

T = ship's calculative draft = 15.25 FT = 183 IN

$$I_{\text{keel}} = 2537275. \text{ KIPS} \cdot \text{SEC}^2 \cdot \text{IN}$$

$I_{xx} = (W/g) \cdot k_{xx}^2$  = mass moment of inertia about the roll axis

$$I_{xx} = 1449223. \text{ KIPS} \cdot \text{SEC}^2 \cdot \text{IN}$$

W = ship displacement = 5600 TONS = 12544 KIPS

g = accel. of gravity = 386.09 IN/SEC<sup>2</sup>

$k_{xx} = 0.64 \cdot B/2$  Radius of gyration about the roll axis  
from Introduction to Naval Architecture Page 272  
for Destroyer type ships

B = ship's beam = 55 FT = 660 IN

$k_{xx} = 211.2 \text{ IN}$



# "3DOFRUB" USS Leahy Input Data File

\*\*\*SHIP/SUB DRYDOCK BLOCKING SYSTEM\*\*\* DATA FILE: B:LEAHTRUE.DAT

## \*\*\*INPUT FILE DATA\*\*\*

SHIP NAME: USS LEAHY CG-16  
DISCRIPTION OF ISOLATORS IF USED: NO ISOLATOR ALL BILINEAR  
DISCRIPTION OF BUILDUP: 12 SPACING COMPOSITE  
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES  
DISCRIPTION OF DAMPING: 5 % DAMPING  
LOCATION OF DRYDOCK BEING STUDIED: LONG BEACH NAVAL SHIPYARD DD # 3  
NAVSEA DOCKING DRAWING NUMBER: BUSHIPS 1948741 REV.1  
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: LEAHKHEL.WK1 LEAHKVEL.WK1 ETC.  
MISC. COMMENTS: LEAHTRUE.DAT 1318 28 JAN 88

SHIP WEIGHT (KIPS)	W= 12544
HEIGHT OF KG (IN)	H= 266.264
MOMENT OF INERTIA (KIPS*IN*SEC^2)	Ik= 2537275
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)	Kvs= 3557.849
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	Kvsp= 3243.91
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)	KVK= 65590.62
HEIGHT OF WALE SHORES (IN)	AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)	KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHS= 8635.889
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHK= 41447.53
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KSHP= 3351.12
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KKHP= 19362.33
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS)	QD1= 29970.73
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS)	QD2= 4015.69
RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS)	QD3= 2097.55
GRAVITATIONAL CONSTANT (IN/SEC 2)	GRAV= 386.09
SIDE BLOCK WIDTH (IN)	SBW= 126
KEEL BLOCK WIDTH (IN)	KBW= 108
SIDE BLOCK HEIGHT (IN)	SBH= 181
KEEL BLOCK HEIGHT (IN)	KBH= 150
BLOCK ON BLOCK FRICTION COEFFICIENT	U1= .3
HULL ON BLOCK FRICTION COEFFICIENT	U2= .5
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)	BR= 289
SIDE PIER CAP PROPORTIONAL LIMIT	SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT	KCPL= .45
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2)	SAREA= 7054
TOTAL KEEL PIER CONTACT AREA (IN^2)	KAREA= 60480
PERCENT CRITICAL DAMPING	ZETA= .05
HULL NUMBER (XXXX)	HULL= 16
SYSTEM NUMBER (XXX)	NSYS= 1
CAP ANGLE (RAD)	BETA= .435

## Leahy Cap Angle Regression Analysis

CAP ANGLE ANALYSIS

\*\* PAGE 1 \*\*

\*\* 14-Mar-88 \*\*

USS LEAHY CG-16 ANALYSIS  
DURING THE 1 OCT 87 WHITTIER EARTHQUAKE  
EXCITED BY THE DRY DOCK # 2 ACCELERATION TIME HISTORY

CAP ANGLE ANALYSIS:

TRANSVERSE DISTANCE BETWEEN B AND C HEIGHTS = 18 IN

BLOCK #	CAP ANGLE (RAD)	CAP ANGLE (DEG)	B HEIGHT (FT)	B HEIGHT (IN)	B TOTAL HEIGHTS (IN)	B TOTAL (IN)	C HEIGHT (FT)	C HEIGHT (IN)	C TOTAL HEIGHTS (IN)	FAILURE MODE
15	0.587	33.4	2	24	24	30.75	2	4	2	40.25 SBSLIDE
14	0.485	27.8	2	24	24	27.13	2	11	2	35.25 SBSLIDE
13	0.426	24.4	1	11	5	27.63	2	6	7	30.88 SBSLIDE
7	0.386	22.1	1	11	7	23.88	2	6	4	30.50 SBSLIDE
12	0.386	22.1	1	9	0	21.00	2	3	5	27.63 SBSLIDE
6	0.378	21.6	2	0	0	24.75	2	7	2	31.25 SBSLIDE
1	0.370	21.2	2	9	6	45.75	4	4	1	52.13 SBSLIDE
4	0.370	21.2	2	0	0	30.00	3	0	3	36.38 SBSLIDE
3	0.362	20.7	2	10	2	34.25	3	4	4	40.50 SBLIFTOFF
2	0.362	20.7	2	2	3	39.38	3	9	5	45.63 SBLIFTOFF
5	0.362	20.7	2	3	1	27.13	2	9	3	33.38 SBLIFTOFF
10	0.315	18.1	1	5	0	17.00	1	10	4	22.50 SBLIFTOFF
9	0.300	17.2	1	2	4	15.50	1	8	6	20.75 SBLIFTOFF
8	0.292	16.9	1	3	1	15.13	1	8	2	20.25 SBLIFTOFF
11	0.285	16.3	1	7	0	19.00	2	0	0	24.00 SBLIFTOFF

CAP ANGLE (DEG)	FAILED SLIDING DOZ	REGRESS DATA	MEASURED BLOCK DISPLACEMENT (IN)
-----------------------	--------------------------	-----------------	--

33.40	47.0%	45.4%	1.500	Regression Output: Constant: 0.071953 Std Err of Y Est: 0.058128 R Squared: 0.962758 No. of Observations: 12 Degrees of Freedom: 10 Y Coefficient(s): -0.05622 Std Err of Coef: 0.003496
27.78	70.0%	77.0%	1.500	
24.54	90.0%	94.7%		
24.41	92.0%	95.9%		
22.09	116.6%	109.0%	0.750	
21.64	116.6%	111.5%	0.656	
21.19	116.6%	114.5%	0.375	
20.73	125.6%	116.6%	0.375	
18.07	134.6%	131.6%		
17.20	134.6%	126.5%		
16.77	134.6%	129.9%	0.375	
16.34	134.6%	141.7%	0.125	

# "3DOFRUB" USS Leahy Output File

\*\*\*\* System 1 \*\*\*\*

\*\* Hull 16 \*\*

## \* Ship Parameters \*

Weight	Moment of Inertia	K.G.
15232.0 kips	3038013.0 kips-in-sec2	180.0 ins

## \* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
181.0 ins	168.0 ins	150.0 ins	108.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
289.0 ins	.0 ins	.0 kips/in	.426 rad
1Side Side Pier Contact Area	Total Keel Pier Contact Area	kkhp	
7056.0 in2	60480.0 in2	19362.3 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kshp	kvsp
.300	.500	3351.1 kips/in	3243.9 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	QD1	
.700 kips/in2	.450 kips/in2	29370.7 kips	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness	QD2	
9557.9 kips/in	8635.9 kips/in	4015.7 kips	
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness	QD3	
65590.6 kips/in	41447.5 kips/in	2097.6 kips	

## \* System Parameters and Inputs \*

Earthquake Used is 1 OCT 87 WHITTIER CA

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT  
Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio	Data Time Increment
1.000	.010 sec

Gravitational Constant	% System Damping
386.09 in/sec2	5.00 %

## Mass Matrix

39.4519	.0000	7101.3494
.0000	39.4519	.0000
7101.3494	.0000	3038013.0000

## Damping Matrix

131.3605	.0000	7408.0983
.0000	132.8067	.0000
7408.0983	.0000	3426523.9438

# Stiffness Matrix

58719.3100	.0000	588425.1800
.0000	84706.3200	.0000
588425.1800	.0000	388054529.8468

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	11.266 rad/sec	50.533 rad/sec	46.337 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	11.251 rad/sec	50.469 rad/sec	46.279 rad/sec

For Earthquake Acceleration of 100.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.013138			13.77
Maximum Y		-.005077		6.16
Maximum Rotation			.000945	9.11
Side block sliding	.011768	.000990	.000856	9.07

For Earthquake Acceleration of 90.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.011824			13.77
Maximum Y		-.004570		6.16
Maximum Rotation			.000851	9.11

No failures occurred.

For Earthquake Acceleration of 99.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.013007			13.77
Maximum Y		-.005027		6.16
Maximum Rotation			.000936	9.11
Side block sliding	.011650	.000981	.000848	9.07

For Earthquake Acceleration of 98.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012876			13.77
Maximum Y		-.004976		6.16
Maximum Rotation			.000926	9.11
Side block sliding	.011532	.000971	.000839	9.07

For Earthquake Acceleration of 97.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012744			13.77
Maximum Y		-.004925		6.16
Maximum Rotation			.000917	9.11
Side block sliding	.011415	.000961	.000830	9.07

For Earthquake Acceleration of 96.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012613			13.77
Maximum Y		-.004874		6.16
Maximum Rotation			.000907	9.11
Side block sliding	.011507	.001823	.000856	9.08

For Earthquake Acceleration of 95.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012481			13.77
Maximum Y		-.004824		6.16
Maximum Rotation			.000898	9.11
Side block sliding	.011387	.001804	.000847	9.06

For Earthquake Acceleration of 94.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012350			13.77
Maximum Y		-.004773		6.16
Maximum Rotation			.000889	9.11
Side block sliding	.011267	.001785	.000838	9.08

For Earthquake Acceleration of 93.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012219			13.77
Maximum Y		-.004722		6.16
Maximum Rotation			.000879	9.11
Side block sliding	.011091	.002500	.000854	9.09

For Earthquake Acceleration of 92.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.012087			13.77
Maximum Y		-.004671		6.16
Maximum Rotation			.000870	9.11
Side block sliding	.010972	.002473	.000845	9.09

For Earthquake Acceleration of 91.00 % of the 1 OCT 87 WHITTIER CA

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.011958			13.77
Maximum Y		-.004600		6.16
Maximum Rotation			.000860	9.11

No failures occurred.

#### APPENDIX 4

1. California Division of Mines and  
Geology Report on 1 October 1987  
Whittier
2. Survivability Comparison  
Spreadsheets

California Division of Mines and  
Geology Report on 1 October 1987  
Whittier Earthquake . . . . .

STATE OF CALIFORNIA - THE RESOURCES AGENCY  
DEPARTMENT OF CONSERVATION  
DIVISION OF MINES AND GEOLOGY  
OFFICE OF STRONG MOTION STUDIES  
630 MERCUT DRIVE  
SACRAMENTO, CA 95814  
(PHONE 916-322-3105)

GEORGE DRUENIAN, Geologist



*Handwritten:*  
Prof. M. S. Lefter  
USC / Civil Eng  
LA, CA  
213-741-2987

October 3, 1987

To : Strong Motion Data Users

From : Tony Shakal and Staff *Tony Shakal*  
California Strong Motion Instrumentation Program (CSMIP)  
Division of Mines and Geology/Department of Conservation

Subject: CSMIP Records from Whittier Earthquake of October 1, 1987

Accelerograms of particular interest recorded at CSMIP stations during the October 1 earthquake near Whittier, 15 km east of downtown Los Angeles, are attached. Over 35 records have been recovered at this time; record recovery from outlying stations is still underway. We estimate that over 100 CSMIP stations have recorded the earthquake.

The map in Figure 1 shows the locations of the stations for which records are included here and described below. The map also shows the locations of some of the other CSMIP stations from which records are being recovered. Table 1 lists preliminary station epicentral distances and, when available, peak acceleration values.

Ground-Response Stations:

- o Alhambra - Closest CSMIP station to the epicenter (7 km); instrument in a 1-story school.
- o Oregon Park - Largest CSMIP ground acceleration, 45% g horizontal, was recorded at this station approximately 10 km from the epicenter. The instrument is in a small building.
- o San Marino - Closest station to northwest, relatively low amplitude (20% g).
- o Downey, Inglewood, 116th St. School - These records from close-in freefield stations to the west of the epicenter are also included for reference.

Structures:

- o Admin. Bldg. - Cal State Univ LA. Nine-story reinforced concrete building about 10 km from the epicenter with a "soft first-story" design very similar to the Imperial County Service Building in El Centro. Maximum acceleration of about 40% g at the base, and 50% g at the roof. For comparison, the 1979 Imperial County Services Building record had a peak value of about 35% g at the base, and 60% g at the roof. The CSULA record is shorter in duration, and has less long period energy than the 1979 record. This CSULA building is near the parking structure where the news reported a fatality from a falling concrete slab.
- o Los Angeles - Sears Warehouse. Large 5-story reinforced-concrete frame building about 14 km from the epicenter. Peak acceleration was 18% g at the base and 24% g at the roof.
- o Burbank - Records from two buildings in the Burbank area, 25 km northwest of the epicenter are included. A 6-story steel frame building had a base acceleration of about 25% g, and roof acceleration of 30% g. A nearby 10-story reinforced concrete building had a roof acceleration of 55%.

Although definitive patterns await further data, it appears that San Marino, south of Pasadena, had relatively low shaking (20% g) though only 10 km from the epicenter. Many more distant stations have greater amplitudes. Pomona, 30 km east of the epicenter, had only 5% ground acceleration (record not shown here), much lower than stations at a similar distance to the West. A low acceleration record (5% g) was recorded at the base-isolated County building in Rancho Cucamonga. Some of the buildings from which records were recovered suffered damage during the earthquake; damage information is incomplete at this time.

A standard data report on all CSMIP records will be completed in several weeks. To allow rapid distribution of these records, copies are being sent to only a subset of our normal mailing list. You may wish to make more copies to distribute to your colleagues.



TABLE 1

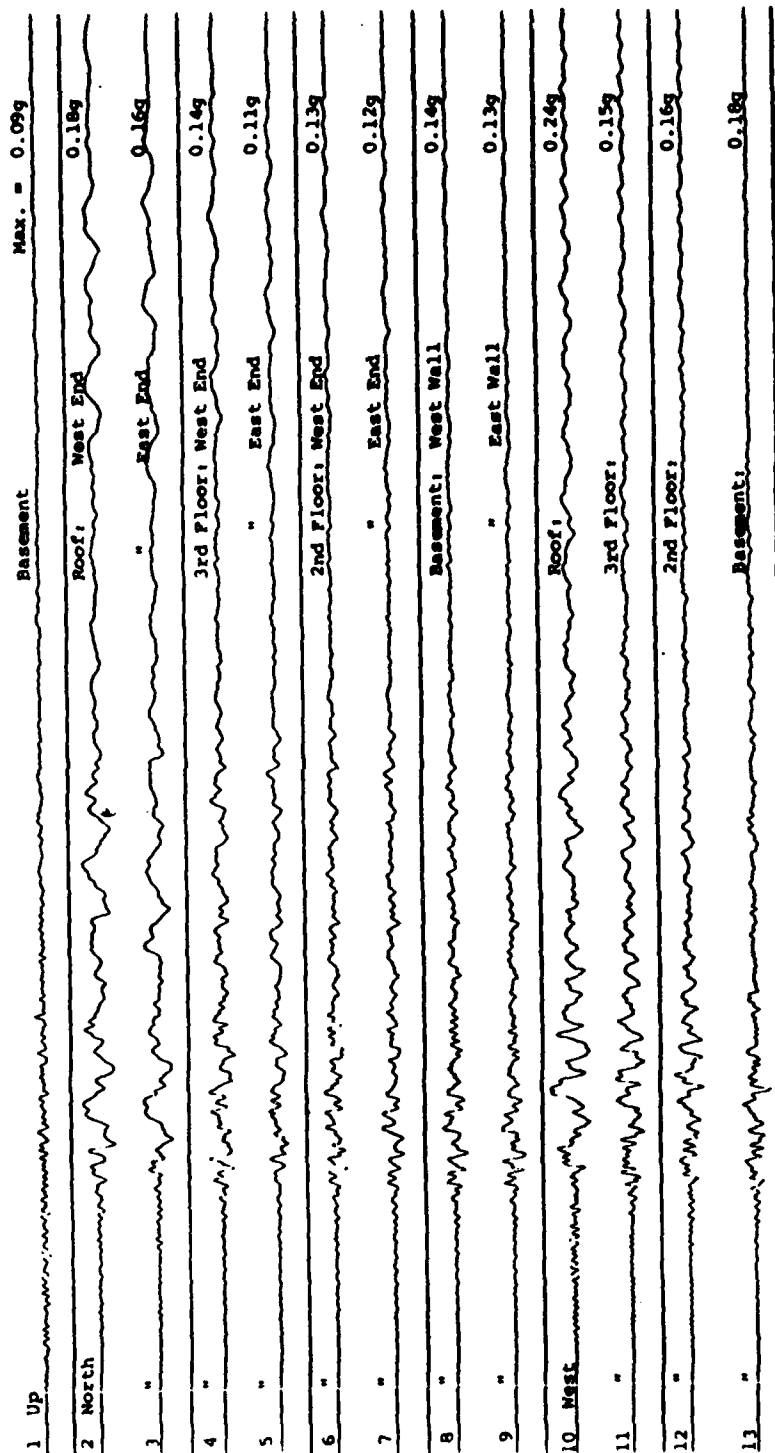
CALIFORNIA STRONG-MOTION INSTRUMENTATION PROGRAM (CIMP)  
DATA RECOVERED FROM RECEIVED EARTHQUAKES  
(File last updated: 3 October 1987, 12:00 PM)

Earthquake in Whittier Area, east of Los Angeles  
1 October 1987, 07:42 PDT -5.8 ML (DMG)  
Epicenter (Preliminary): 34.06N, 118.00W (CIT)

Stn.	Station Name	N. Lat	W. Long	Epicentral Dist (km)	As*	Max. Acceleration
24461	Alhambra - Fremont School	34.070	118.150	7	(201)	0.40g Horiz., 0.20g Vert.
24401	San Marino - St. Academy	34.115	118.130	8	(321)	0.20g H, 0.10g V
24468	L.A. - CURE Admin. Building	34.067	118.168	9	(277)	Ground: 0.30g H, 0.10g V Structure: 0.40g H, 0.50g V
24406	L.A. - Obregon Park	34.037	118.178	10	(256)	0.45g H, 0.15g V
24402	Altadena - Eaton Canyon Park	34.177	118.096	13	(352)	
24463	L.A. - Sears Roebuck	34.020	118.223	14	(256)	Ground: 0.10g H, 0.09g V Structure: 0.20g V
16368	Downey	33.924	118.167	17	(210)	0.20g H, 0.17g V
24399	Mc. Wilson	34.224	118.057	19	(5)	
14403	L.A. - 116th St. School	33.929	118.260	22	(230)	0.40g H, 0.11g V
23210	Cogswell Dam	34.245	117.964	23	(26)	
24236	L.A. - Hollywood Storage Bldg.	34.090	118.330	25	(278)	Ground: 0.12g H, 0.04g V Structure: 0.22g H
24303	L.A.-Hollywood Stor. Bldg. FF	34.090	118.339	25	(278)	0.21g H, 0.06g V
23320	Puddingstone Dam	34.091	117.808	25	(81)	Ground: 0.07g H, 0.04g V Structure: 0.18g H, 0.09g V
14196	Inglewood-Union Oil	33.905	118.279	25	(228)	0.20g H, 0.08g V
24370	Burbank - Calif. Fed. Savings	34.185	118.308	26	(303)	Ground: 0.22g H, 0.10g V Structure: 0.30g H
24385	Burbank - Pacific Manor	34.187	118.311	26	(303)	Ground: 0.26g H, 0.04g V Structure: 0.50g H
24464	L.A. - North Hollywood Sheraton Hotel	34.138	118.359	26	(209)	Ground: 0.11g H, 0.08g V Structure: 0.16g H
25511	Pomona - First Fed. Savings	34.056	117.748	30	(90)	Ground: 0.05g H, 0.04g V Structure: 0.16g H
25525	Pomona - 4th & Locust FF	34.056	117.748	30	(90)	Ground: 0.07g H, 0.04g V
14311	Long Beach - State Univ. Engineering Bldg.	33.783	118.112	31	(186)	Triggered
14241	Long Beach - Recreation Park	33.778	118.133	32	(190)	Triggered
24231	L.A.-UCLA Math.-Science Bldg.	34.069	118.442	34	(272)	Triggered
14533	Long Beach - City Hall	33.760	118.195	34	(199)	Triggered
14323	Long Beach-Harbor Admin. Bldg.	33.755	118.200	36	(199)	Triggered
14395	Long Beach-Harbor Admin. FF	33.754	118.200	36	(199)	Triggered
24327	Shoreline Oaks-Union Bank Bldg.	34.154	118.465	38	(207)	Triggered
14406	L.A. - Vincent Thomas Bridge	33.750	118.271	39	(208)	
24087	Arleta - San Fernando	34.236	118.439	39	(301)	0.09g H, 0.09g V
13122	Featherly Park	33.869	117.709	40	(122)	
24386	Van Nuys - Holiday Inn	34.221	118.471	41	(296)	Triggered
24207	Pasadena Dam	34.334	118.396	43	(316)	
24336	Tarzana-Coder Hill Nursery &	34.160	118.530	44	(205)	Triggered
24514	Sylmar-Olive View Med. Ctr.	34.326	118.444	45	(311)	
23497	Rancho Cucamonga - Law & Just. Center	34.104	117.574	47	(84)	Ground: 0.03g H Structure: 0.04g H

\* Asimuth from earthquake epicenter to station, CN from H, 0-360 deg.

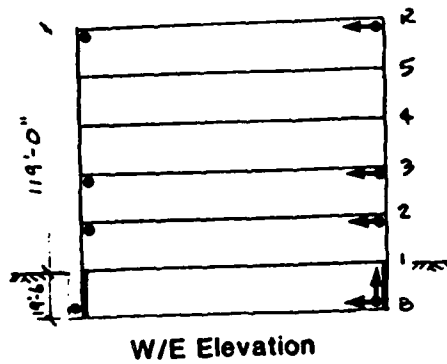
Los Angeles - Sears Warehouse  
(CSHIP Station No. 24463)



1 sec

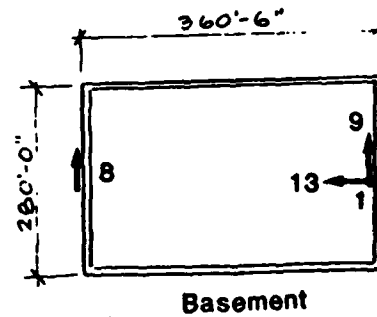
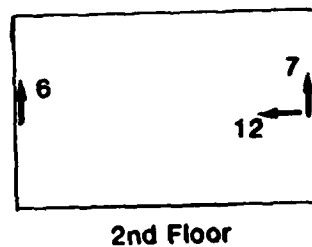
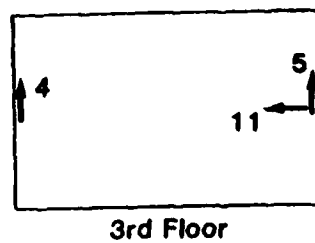
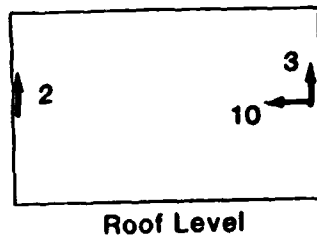
Los Angeles - Sears Warehouse  
(CSMP Station No. 24463)

INSTRUMENTATION LAYOUT



Ductile Reinforced Concrete  
Perimeter Frame Designed in  
Accordance with the 1970 Los  
Angeles Building Code

Designed in 1970



11-1) 5431545 JO MOSI 196300.

250

HULL #	TYPE SYSTEM	REGRESS CURVE DATA
616	CONF 8 FT	0.063153
616	CONF 16 FT	0.074323
616	TIMBER 8 FT	0.068653
616	TIMBER 16 FT	0.108367
616	TIMB SIDE COMP KEEL 16 FT	0.108329
726	CONF 8 FT	0.144275
726	CONF 12 FT	0.079635
726	CONF 16 FT	0.063838
637	CONF SIDE TIMB KEEL 12 FT	0.061895
637	CONF SIDE TIMB KEEL 12 FT	0.073459
637	CONF SIDE TIMB KEEL 16 FT	0.062206

MEAN	SIGMA	BILINEAR	LINEAR	1*RU	LINE	REGRESS
FREQ	%	%	%	%	TOTAL	LINE
NO.	SURVIVED	SURVIVED	SURVIVED	SURVIVED		

0.57	24%			24%	25%	Regression Output:
0.62	33%			33%	25%	25%Constant 0.249848
0.64	33%			33%	25%	25%Std Err of Y Est 0.053504
0.45	21%			21%	25%	25%R Squared 0.000064
0.45	10%			10%	25%	25%No. of Observations 44
1.54	36%			26%	25%	25%Degrees of Freedom 42
1.27	27%			27%	25%	
1.11	33%			23%	25%	25% Coefficient(s) 0.001465
0.93	33%			33%	25%	25%Std Err of Coef. 0.028153
1.09	28%			28%	25%	
0.98	29%			29%	25%	
1.02		15%		15%	25%	
0.73		22%		22%	25%	
0.79		29%		29%	25%	
0.56		26%		26%	25%	
0.56		21%		21%	25%	
1.46		30%		30%	25%	
1.19		24%		24%	25%	
1.04		23%		23%	25%	
0.99		22%		22%	25%	
1.14		24%		24%	25%	
1.00		20%		20%	25%	
1.02			19%	19%	25%	
0.73			33%	33%	25%	
0.79			33%	33%	25%	
0.56			29%	29%	25%	
0.56			21%	21%	25%	
1.46			30%	30%	25%	
1.19			24%	24%	25%	
1.04			23%	23%	25%	
0.99			27%	27%	25%	
1.14			26%	26%	25%	
1.00			24%	24%	25%	
0.67			32%	32%	25%	
0.47			29%	29%	25%	
0.62			42%	42%	25%	
0.43			39%	39%	25%	
0.43			28%	28%	25%	
1.11			27%	27%	25%	
1.31			26%	26%	25%	
0.79			32%	32%	25%	
0.75			26%	26%	25%	
0.55			24%	24%	25%	
0.74			35%	35%	25%	

## APPENDIX 5

1. "3DOFRUB" Isolator (EL Centro)  
Input Data File
2. "3DOFRUB" Isolator (EL Centro)  
Output File
3. "3DOFRUB" Isolator (NORM DD2)  
Input Data File
4. "3DOFRUB" Isolator (NORM DD2)  
Output File
5. Isolator Equivalent Modulus  
Stiffness Spreadsheets
6. Required Isolator Characteristics  
Spreadsheet

**"3DOFRUB" Isolator (EL Centro)**  
**Input Data File . . . . .**

\*\*\*SHIP/SUB DRYDOCK BLOCKING SYSTEM\*\*\* DATA FILE: B:5891G000.DAT

\*\*\*INPUT FILE DATA\*\*\*

SHIP NAME: LAFAYETTE SSBN 616  
 DISCRPTION OF ISOLATORS IF USED: 6" RUBBER CAP W/ ISOLATORS  
 DISCRPTION OF BUILDUP: 8 SPACING COMPOSITE  
 DISCRPTION OF WALE SHORES USED: NO WALE SHORES  
 DISCRPTION OF DAMPING: 8% DAMPING  
 LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION  
 NAVSEA DOCKING DRAWING NUMBER: 845-10000-00  
 REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: S15KVE1.WK1 ETC.  
 MISC. COMMENTS: 5891R150.DAT 1245 15 FEB 88

PRESS ANY KEY TO CONTINUE...

SHIP WEIGHT (KIPS)	W= 16369.9
HEIGHT OF KG (IN)	H= 193
MOMENT OF INERTIA (KIPS*IN*SEC^2)	Ik= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)	Kvs= 1303.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	Kvsp= 4093.1
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)	KVK= 8062.08
KEEL PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	KVKP= 22101.31
HEIGHT OF WALE SHORES (IN)	AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)	KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHS= 55
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHK= 271.91
SIDE PIER HORIZONTAL PLASTIC STIFFNESS (KIPS/IN)	KSHP= 11.12
KEEL PIER HORIZONTAL PLASTIC STIFFNESS (KIPS/IN)	KKHP= 42.02
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS)	QD1= 135.08
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS)	QD2= 18.4
RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS)	QD3= -1773.63
RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS)	QD4= -9577.03
GRAVITATIONAL CONSTANT (IN/SEC^2)	GRAV= 386.09

PRESS ANY KEY TO CONTINUE...

SIDE BLOCK WIDTH (IN)	SBW= 999
KEEL BLOCK WIDTH (IN)	KBW= 999
SIDE BLOCK HEIGHT (IN)	SBH= 75
KEEL BLOCK HEIGHT (IN)	KBH= 61
BLOCK ON BLOCK FRICTION COEFFICIENT	U1= 9
HULL ON BLOCK FRICTION COEFFICIENT	U2= .75
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)	BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT	SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT	KCPL= .7
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2)	SAREA= 8352
TOTAL KEEL PIER CONTACT AREA (IN^2)	KAREA= 55440
PERCENT CRITICAL DAMPING	ETA= .08
HULL NUMBER (XXXX)	HULL= 616
SYSTEM NUMBER (XXX)	NSYS= 891
CAP ANGLE (RAD)	BETA= .377

PRESS ANY KEY TO CONTINUE...

**"3DOFRUB" Isolator (EL Centro)**  
**Output File . . . . .**

\*\* Hull 616 \*\*

\* Ship Parameters \*

Weight	Moment of Inertia	L.G.
16889.9 kips	2410451.0 kips-in-sec <sup>2</sup>	193.0 ins

\* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
75.0 ins	999.0 ins	61.0 ins	999.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
144.0 ins	.0 ins	.0 kips/in	.377 rad
1Side Side Pier Contact Area	Total Keel Pier Contact Area	kkip	
8352.0 in <sup>2</sup>	55440.0 in <sup>2</sup>	42.0 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kshp	kvsp
9.000	.750	11.1 kips/in	4093.1 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	kvkp	
.700 kips/in <sup>2</sup>	.700 kips/in <sup>2</sup>	22101.3 kips/in	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness		
1303.2 kips/in	55.0 kips/in		
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness		
3062.1 kips/in	271.9 kips/in		
QD1	QD2	QD3	QD4
135.1 kips	18.4 kips	-1773.6 kips	-9577.0 kips

\* System Parameters and Inputs \*

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is  
Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio      Data Time Increment

1.000      .010 sec

Gravitational Constant      % System Damping

386.09 in/sec<sup>2</sup>      8.00 %

Mass Matrix

42.3992	.0000	8183.0420
.0000	42.3992	.0000
8183.0420	.0000	2410451.0000

Damping Matrix

17.2898	.0000	1823.2557
.0000	107.8096	.0000
1823.2557	.0000	728995.2548



# Stiffness Matrix

381.9100	.0000	1540.0000
.0000	10668.5400	.0000
1540.0000	.0000	10105627.1325

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	1.784 rad/sec	5.864 rad/sec	15.863 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	1.778 rad/sec	5.845 rad/sec	15.812 rad/sec

For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	8.683955			8.25
Maximum Y		-.516443		5.63
Maximum Rotation			-.009067	6.47
Side block crushing	.848398	-.303353	.008030	5.86

For Earthquake Acceleration of 90.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-6.332777			6.97
Maximum Y		-.398401		5.61
Maximum Rotation			-.012778	7.34
Side block liftoff	-1.519886	.095785	-.012452	7.30
Side block crushing	-2.340034	-.101646	-.010844	7.24

For Earthquake Acceleration of 80.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.730884			6.96
Maximum Y		-.357898		5.60
Maximum Rotation			-.011979	7.32
Side block liftoff	-1.161818	.124281	-.011965	7.31
Side block crushing	-1.938861	-.103703	-.010878	7.24

For Earthquake Acceleration of 70.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.133748			6.95
Maximum Y		-.313161		5.60
Maximum Rotation			-.010912	7.31

No failures occurred.

For Earthquake Acceleration of 79.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.666482			6.96
Maximum Y		-.353425		5.60
Maximum Rotation			-.011854	7.32
Side block liftoff	-1.062667	.153909	-.011854	7.32
Side block crushing	-1.922698	-.102559	-.010792	7.24

For Earthquake Acceleration of 78.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.614749			6.95
Maximum Y		-.348951		5.60
Maximum Rotation			-.011776	7.32
Side block liftoff	-1.036571	.152184	-.011776	7.32

For Earthquake Acceleration of 77.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.542802			6.95
Maximum Y		-.344477		5.60
Maximum Rotation			-.011750	7.31
Side block liftoff	-.996025	.150506	-.011749	7.32

For Earthquake Acceleration of 76.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.484800			6.95
Maximum Y		-.340003		5.60
Maximum Rotation			-.011522	7.31
Side block liftoff	-.929225	.171991	-.011477	7.23

For Earthquake Acceleration of 75.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.415882			6.95
Maximum Y		-.335530		5.60
Maximum Rotation			-.011375	7.31
Side block liftoff	-.917363	.169728	-.011331	7.23

For Earthquake Acceleration of 74.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
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Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.395319			6.95
Maximum Y		-.331056		5.60
Maximum Rotation			-.011318	7.31
Side block liftoff	-.318169	.193618	-.011208	7.34

For Earthquake Acceleration of 73.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.337773			6.95
Maximum Y		-.326582		5.60
Maximum Rotation			-.011196	7.31
Side block sliding	-.726184	.190748	-.010986	7.35
Side block overturning	-.726184	.190748	-.010986	7.35

For Earthquake Acceleration of 72.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-5.269186			6.95
Maximum Y		-.322108		5.60
Maximum Rotation			-.011063	7.31

No failures occurred.

**"3DOFRUB" Isolator (NORM DD2)  
Input Data File . . . . .**

\*\*\*SHIP/SUB DRYDOCK BLOCKING SYSTEM\*\*\* DATA FILE: B:SS93DD11.DAT

\*\*\*INPUT FILE DATA\*\*\*

SHIP NAME: LAFAYETTE SSBN 616  
DISCRIPTION OF ISOLATORS IF USED: 6" RUBBER CAP W/ ISOLATORS  
DISCRIPTION OF BUILDUP: 8 SPACING COMPOSITE  
DISCRIPTION OF WALE SHORES USED: NO WALE SHORES  
DISCRIPTION OF DAMPING: 8% DAMPING  
LOCATION OF DRYDOCK BEING STUDIED: DD2 LENS  
NAVSEA DOCKING DRAWING NUMBER: 845-2006640  
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: S15KVE1.WK1 ETC.  
MISC. COMMENTS: SS93DD11.DAT 1255 17 FEB 88

PRESS ANY KEY TO CONTINUE...

SHIP WEIGHT (KIPS)	W= 16369.9
HEIGHT OF KG (IN)	H= 193
MOMENT OF INERTIA (KIPS*IN*SEC^2)	Ik= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)	Kvs= 1303.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	Kvsp= 4093.1
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)	KVK= 8062.08
KEEL PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	KVKP= 22101.31
HEIGHT OF WALE SHORES (IN)	AAA= 0
WALE SHORE STIFFNESS (KIPS/IN)	KS= 0
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHS= 44
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHE= 217.58
SIDE PIER HORIZONTAL PLASTIC STIFFNESS (KIPS/IN)	KSHP= 8.299999
KEEL PIER HORIZONTAL PLASTIC STIFFNESS (KIPS/IN)	KHEP= 33.62
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS)	QD1= 108.06
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS)	QD2= 14.72
RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS)	QD3= -1773.63
RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS)	QD4= -9577.03
GRAVITATIONAL CONSTANT (IN/SEC^2)	GRAV= 386.09

PRESS ANY KEY TO CONTINUE...

SIDE BLOCK WIDTH (IN)	SBW= 999
KEEL BLOCK WIDTH (IN)	KBW=
SIDE BLOCK HEIGHT (IN)	SBH= 75
KEEL BLOCK HEIGHT (IN)	KBH= 61
BLOCK ON BLOCK FRICTION COEFFICIENT	U1= 9
HULL ON BLOCK FRICTION COEFFICIENT	U2= .75
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)	BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT	SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT	KCPPL= .7
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2)	SAREA= 8352
TOTAL KEEL PIER CONTACT AREA (IN^2)	KAREA= 55440
PERCENT CRITICAL DAMPING	ZETA= .08
HULL NUMBER (XXXX)	HULL= 616
SYSTEM NUMBER (XXX)	NSYS= 890
CAP ANGLE (RAD)	BETA= .377

PRESS ANY KEY TO CONTINUE...

"3DOFRUB" Isolator (NORM DD2)  
Output File . . . . .

\*\* Hull 616 \*\*

\* Ship Parameters \*

Weight	Moment of Inertia	P.G.
16369.9 kips	2410451.0 kips-in-sec <sup>2</sup>	193.0 ins

\* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
75.0 ins	999.0 ins	61.0 ins	999.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
144.0 ins	.0 ins	.0 kips/in	.377 rad
Side Side Pier Contact Area	Total Keel Pier Contact Area	kkhp	
8352.0 in <sup>2</sup>	55440.0 in <sup>2</sup>	33.6 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kskp	kvsp
9.000	.750	8.9 kips/in	4093.1 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	kvkp	
.700 kips/in <sup>2</sup>	.700 kips/in <sup>2</sup>	22101.3 kips/in	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness		
1303.2 kips/in	44.0 kips/in		
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness		
8062.1 kips/in	217.5 kips/in		
DD1	DD2	DD3	DD4
102.1 kips	14.7 kips	-1773.6 kips	-9577.0 kips

\* System Parameters and Inputs \*

Earthquake Used is 1 OCT 87 WHITTIER \* 10.94

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT  
Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio	Data Time Increment
1.000	.010 sec

Gravitational Constant	% System Damping
386.09 in/sec <sup>2</sup>	3.00 %

Mass Matrix

42.3992	.0000	3183.0420
.0000	42.3992	.0000
3183.0420	.0000	2410451.0000

Damping Matrix

15.7037	.0000	1733.8344
.0000	107.6096	.0000
1733.8344	.0000	730340.4420

# Stiffness Matrix

305.5300	.0000	1232.0000
.0000	10662.5400	.0000
1232.0000	.0000	10105319.1325

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	1.722 rad/sec	5.438 rad/sec	15.801 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	1.717 rad/sec	5.416 rad/sec	15.812 rad/sec

For Earthquake Acceleration of 100.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	6.429004			16.72
Maximum Y		.293265		5.72
Maximum Rotation			-.019115	14.50
Side block liftoff	2.744572	.043471	.013135	13.86
Side block crushing	2.744572	.043471	.013135	13.86

For Earthquake Acceleration of 90.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.717000			13.73
Maximum Y		.262813		5.72
Maximum Rotation			.015841	17.17
Side block sliding	-1.967609	.006875	.013540	16.18
Side block overturning	-1.967609	.006875	.013540	16.18
Side block liftoff	-1.962900	.025600	.013302	16.19
Side block crushing	-.720489	-.055832	-.011755	14.45

For Earthquake Acceleration of 80.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.310249			13.72
Maximum Y		.232091		5.72
Maximum Rotation			.015249	17.17
Side block liftoff	.615975	.005610	.013536	17.08
Side block crushing	-.065472	-.047203	-.011620	14.35

For Earthquake Acceleration of 70.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-4.878304			9.09
Maximum Y		.200566		5.72
Maximum Rotation			.013874	17.16
Side block sliding	.036936	-.013022	.013215	17.18

Side block overturning	.036986	-.013027	.013670	17.16
Side block liftoff	.154749	.005155	.013670	17.13
Side block crushing	2.330717	-.020743	-.011920	15.54

For Earthquake Acceleration of 60.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.014680			13.77
Maximum Y		.167810		5.72
Maximum Rotation			-.007604	12.17

No failures occurred.

For Earthquake Acceleration of 69.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-4.793266			9.09
Maximum Y		.195318		5.72
Maximum Rotation			.013709	17.16
Side block sliding	-.002265	-.005044	.013709	17.16
Side block overturning	-.002265	-.005044	.013709	17.16
Side block liftoff	.048491	.002213	.013636	17.14
Side block crushing	2.436910	-.023426	-.011937	15.60

For Earthquake Acceleration of 62.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-4.852107			9.09
Maximum Y		.192487		5.72
Maximum Rotation			.013540	17.16
Side block crushing	-1.663434	-.049463	.011728	16.09

For Earthquake Acceleration of 67.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-4.829379			9.09
Maximum Y		.183656		5.72
Maximum Rotation			.013439	17.16
Side block crushing	-1.664839	-.048735	.011693	16.09

For Earthquake Acceleration of 66.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.723670			13.73
Maximum Y		.125186		5.72
Maximum Rotation			.013622	17.16

Maximum Rotation	.594215	.006100	.012700	17.15
Side block liftoff			.012700	17.15
Side block crushing	1.252601	-.013856	-.012157	15.57

For Earthquake Acceleration of 65.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.876296			13.75
Maximum Y		.182341		5.72
Maximum Rotation			.012521	17.15
Side block crushing	.866109	.006280	.012313	17.12

For Earthquake Acceleration of 64.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.787844			13.75
Maximum Y		.178997		5.72
Maximum Rotation			.012185	17.15
Side block crushing	.798469	-.004347	.012171	17.16

For Earthquake Acceleration of 63.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	5.725950			13.75
Maximum Y		.176201		5.72
Maximum Rotation			.011489	17.11

No failures occurred.



# Isolator Equivalent Modulus

17-Feb-8 Stiffness Spreadsheets. . .

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS

ORIGINAL DOCKING DRAWING WITH ALSEES CAP  
AND ISOLATORS

SYSTEM 86

THIS IS A KEEL SYSTEM FOR HULL 816 WITH 4 FT BUILDUP  
8 FOOT CENTERS

ELEMENT # 1 CONCRETE		TRANSVERSE		WEIGHT	
E1	DEPTH	H1	I1	L1	
(PSI)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
4000000	42	48	387072	27	
12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1		
943934156.38	12743111111.1	229376000000	114698000000		
RIGIDITY	TOP	SHEAR	ELEMENT		
G1	CONTACT	STRAIN	SHEAR		
(PSI)	AREA	(IN/IN)	DEFLECTION		
	(IN <sup>2</sup> )		(IN)		
2400000	2016	0.0000002067	0.0000055804		

ELEMENT # 2 DIS ISOLATORS		TRANSVERSE		WEIGHT	
E2	DEPTH	H2	I2	L2	
(PSI)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
699	42	48	387072	27	
12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2		
164952.49383	2226558.6667	40083456	20041728		
RIGIDITY	TOP	SHEAR	ELEMENT		
G2	CONTACT	STRAIN	SHEAR		
(PSI)	AREA	(IN/IN)	DEFLECTION		
	(IN <sup>2</sup> )		(IN)		
70	2016	0.0001967054	0.0018732451		

ELEMENT # 3 DOUGLAS FIR				
E3	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B3	H3	I3	L3
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
175549	42	48	387072	1
12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3	
8.1540E+11	4.0770E+11	2.7180E+11	1.3590E+11	
RIGIDITY	TOP	SHEAR	ELEMENT	
GIP	CONTACT	STRAIN	SHEAR	
(PSI)	AREA	(IN/IN)	DEFLECTION	
	(IN <sup>2</sup> )		(IN)	
12579	2.16	0.0000395584	0.0000395584	

ELEMENT # 4 RUBBER				
E4	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B4	H4	I4	L3
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)
992	42	48	387072	6
12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4	
2.1732E+07	6.3996E+07	2.5598E+08	1.2799E+08	
RIGIDITY	TOP	SHEAR	ELEMENT	TOTAL
GIP	CONTACT	STRAIN	SHEAR	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION	DEFLECTION
	(IN <sup>2</sup> )		(IN)	(IN)
335	1411.2	0.0021134066	0.0126864396	2.0433E-01

F / N		STIFFNESS MATRIX										D
Q1	9.4393E+08	1.2743E+10	-9.4393E+08	1.2743E+10	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	Q1	
M1	1.2743E+10	2.2938E+11	-1.2743E+10	1.1445E+11	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	th1	
Q2	-9.4393E+08	-1.2743E+10	9.4410E+08	-1.2743E+10	-1.6493E+05	2.2263E+06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	Q2	
M2	1.2743E+10	1.1446E+11	-1.2743E+10	2.2942E+11	-2.2263E+06	2.0042E+07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	th2	
Q3	0.0000E+00	0.0000E+00	-1.6493E+05	-2.2263E+06	8.1540E+11	4.0770E+11	-8.1540E+11	4.0770E+11	0.0000E+00	0.0000E+00	Q3	
M3	0.0000E+00	0.0000E+00	2.2263E+06	2.0042E+07	4.0770E+11	2.7184E+11	-4.0770E+11	1.3590E+11	0.0000E+00	0.0000E+00	th3	
Q4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-8.1540E+11	-4.0770E+11	8.1542E+11	-4.0764E+11	-2.13320E+07	6.39959E+07	Q4	
M4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.0770E+11	1.3590E+11	-4.0764E+11	2.7702E+11	-6.39959E+07	1.27929E+08	th4	
Q5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-2.13320E+07	-6.39959E+07	2.13320E+07	-6.39959E+07	Q5	
M5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	6.39959E+07	1.27929E+08	-6.39959E+07	2.55984E+08	th5	

# KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1\*(L1+L2+L3+L4) = -61000 IN\*lbs  
Q2 = M2 = Q3 = M3 = M4 = Q4 = M5  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

55

## SOLVED UNKNOWNNS:

q2= 0.0000122419 in  
th2 0.0000008283 rad

q3 0.0337143375 in -B1 -B2  
-1003.86391667 -34060.4635

th3 0.0020465601 rad

q4 0.0000000000 in -B3 -B4  
-1003.86391667 -34060.4635

th4 0.0020465601 rad

q5 0.0482283934 in -B5 -B6  
-894628.95774 -2818464.4599

th5 0.0020925238 rad

K (BEND HORIZ) FOR 1 KEEL BLOCK = 27963.465505 lbs/in 27.963465505 KIPS/IN

K (BEND HORIZ) ALL KEEL BLOCKS = 1537990.6028 lbs/in 1537.9906028 KIPS/IN

## MATRIX CHECK:

Q1 = -1000.0000  
M1 = -61000.0000  
Q2 = 0.0000  
M2 = 0.0000  
Q3 = 0.0000  
M3 = 0.0000  
Q4 = 0.0000  
M4 = 0.0000  
Q5 = 1000.0000  
M5 = 0.0000

TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:  
SYSTEM B6 1" RUBBER CAP W/ ISOLATORS

Khk (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk = 3.96 KIPS/IN (PER BLOCK)  
217.53  
Khk = 217.78 KIPS/IN (ENTIRE KEEL BLOCK SYSTEM)

17-FEB-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS

ORIGINAL DOCKING DRAWING WITH RUBBER CAP  
AND ISOLATORS

SYSTEM 86

THIS IS A KEEL SYSTEM FOR HULL 616 WITH 4 FT BUILDUP  
9 FOOT CENTERS

ELEMENT # 1	CONCRETE				
E1	DEPTH	TRANSVERSE		HEIGHT	
(PSI)	B1	H1	I1	L1	
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
1.00E+50	42	48	387072	27	

12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1
2.3598754E+52	3.1857778E+53	5.7344000E+54	2.8672000E+54

RIGIDITY	TOP	SHEAR	ELEMENT
GI*	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
*****	2016	6.2671958E-51	2.2321429E-49

ELEMENT # 2	CAK				
E2	DEPTH	TRANSVERSE		HEIGHT	
(PSI)	B2	H2	I2	L2	
	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
1.00E+50	42	48	387072	6	

12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2
2.1534000E+54	6.4512000E+54	2.5804800E+55	1.2902400E+55

RIGIDITY	TOP	SHEAR	ELEMENT
GI*	CONTACT	STRAIN	SHEAR
(PSI)	AREA	(IN/IN)	DEFLECTION
	(IN <sup>2</sup> )		(IN)
1.74E+49	2016	4.9697175E-50	2.9761905E-49

ELEMENT # 3 DOUGLAS FIR				
E3 (PSI)	DEPTH B3 (IN)	TRANSVERSE H3 (IN)	L3 (IN*4)	HEIGHT L3 (IN)
1.00E+50	42	48	387072	1
12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3	
4.6449E+56	2.3224E+56	1.5483E+56	7.7414E+55	
RIGIDITY G1r (PSI)	TOP CONTACT AREA (IN*2)	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	
1.00E+49	2016	4.9603175E-50	4.9603175E-50	

ELEMENT # 4 DIS ISOLATOR				
E4 (PSI)	DEPTH B4 (IN)	TRANSVERSE H4 (IN)	L4 (IN*4)	HEIGHT L3 (IN)
699	42	48	387072	27
12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4	
1.6495E+05	2.2269E+06	4.0083E+07	2.0042E+07	
RIGIDITY G1r (PSI)	TOP CONTACT AREA (IN*2)	SHEAR STRAIN (IN/IN)	ELEMENT SHEAR DEFLECTION (IN)	TOTAL SHEAR DEFLECTION (IN)
6.99E+01	1411.2	0.0101375791	0.2737146361	2.7371E-01

STIFFNESS MATRIX

F / N D

Q1	2.3598E+52	3.1858E+53	-2.3598E+52	3.1858E+53	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	q1
M1	3.1858E+53	5.7344E+54	-3.1858E+53	2.8672E+54	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	th1
Q2	-2.3598E+52	-3.1858E+53	2.1740E+54	6.1326E+54	-2.1504E+54	6.4512E+54	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	q2
M2	3.1858E+53	2.8672E+54	6.1326E+54	3.1539E+55	-6.4512E+54	1.2902E+55	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	th2
Q3	0.0000E+00	0.0000E+00	-2.1504E+54	-6.4512E+54	4.6664E+56	2.2579E+56	-4.6449E+56	2.3224E+56	0.0000E+00	0.0000E+00	q3
M3	0.0000E+00	0.0000E+00	6.4512E+54	1.2902E+55	2.2579E+56	1.8063E+56	-2.3224E+56	7.7414E+55	0.0000E+00	0.0000E+00	th3
Q4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-4.6449E+56	-2.3224E+56	4.6449E+56	-2.3224E+56	-1.64952E+05	2.22686E+06	q4
M4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.3224E+56	7.7414E+55	-2.3224E+56	1.5483E+56	-2.22686E+06	2.00417E+07	th4
Q5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	-1.64952E+05	-2.22686E+06	1.64952E+05	-2.22686E+06	q5
M5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	2.22686E+06	2.00417E+07	-2.22686E+06	4.00835E+07	th5

# KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1\*(L1+L2+L3+L4) = -61000 IN\*lbs  
Q2 = Q3 = Q4 = Q5 = 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

55

## SOLVED UNKNOWNNS:

q2= 4.8967634E-49 in  
th2 3.3133371E-50 rad

q3 7.0335751E-49 in  
th3 3.7938678E-50 rad  
q4 7.4165558E-49 in  
th4 3.8649148E-50 rad

-B1 -B2  
-1267750 -4048000

-126512000 -169251000

q5 0.024249406 in  
th5 0.0013471892 rad

-959.99999997 -27000

K (BEND HORIZ) FOR 1 KEEL BLOCK = 1.3465384E+51 lbs/in 1.3483384E+48 KIPS/IN

K (BEND HORIZ) ALL KEEL BLOCKS = 7.4158612E+50 lbs/in 7.4158612E+49 KIPS/IN

## MATRIX CHECK:

Q1 = -1000.0000  
M1 = -61000.0000  
Q2 = 0.0000  
M2 = 0.0000  
Q3 = 0.0000  
M3 = 0.0000  
Q4 = 0.0000  
M4 = 0.0000  
Q5 = 1000.0000  
M5 = 0.0000

## TOTAL KEEL BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION: SYSTEM 86 1" RUBBER CAP W/ ISOLATORS

Khk (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khk = 3.36 KIPS/IN (PER BLOCK)  
183.00  
Khk = 184.59 KIPS/IN (ENTIRE KEEL BLOCK SYSTEM)



17-Feb-88

HORIZONTAL STIFFNESS MATRIX FOR 4 LAYERS 1" RUBBER CAP E1  
WITH ISOLATORS

SYSTEM 86 KU  
THIS IS A SIDE BLOCK SYSTEM FOR HULL 618 WITH 5 FT BUILDUP  
16 FOOT CENTERS

ELEMENT # 1					CONCRETE
E1	DEPTH	TRANSVERSE		HEIGHT	
B1	B1	H1	I1	L1	
(PSI)	(IN)	(IN)	(IN <sup>4</sup> )	(IN)	
-----					
4000000	48	42	296352	48	
-----					
12E111/L1*3	6E111/L1*2	4E111/L1	2E111/L1		
-----					
128625000	3087000000	98784000000	49392000000		
-----					
RIGIDITY	TOP	SHEAR	ELEMENT		
GIR	CONTACT	STRAIN	SHEAR		
(PSI)	AREA	(IN/IN)	DEFLECTION		
	(IN <sup>2</sup> )		(IN)		
-----					
2400000	2016	0.0000002067	0.0000099206		
-----					

ELEMENT # 2 DIS ISOLATOR				
E2	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B2	H2	I2	L2
	(IN)	(IN)	(IN^4)	(IN)
-----				
875	23.4	29.7	51086.24235	19
-----				
12E212/L2*3	6E212/L2*2	4E212/L2	2E212/L2	
-----				
78204.628178	742943.96769	9410620.5908	4705311.7954	
-----				
RIGIDITY	TOP	SHEAR	ELEMENT	
GIR	CONTACT	STRAIN	SHEAR	
(PSI)	AREA	(IN/IN)	DEFLECTION	
	(IN^2)		(IN)	
-----				
88	486.426	0.027492087	0.4462496527	
-----				

ELEMENT # 3	DOUGLAS FIR			
BT	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B3	H3	L3	L3
	(IN)	(IN)	(IN*4)	(IN)
95297	12	24	13824	2

12E313/L3*3	6E313/L3*2	4E313/L3	2E313/L3
1.9761E+09	1.9761E+09	2.6048E+09	1.3174E+09

RIGIDITY	TOP	SHEAR	ELEMENT
GIR	CONTACT	STRAIN	SHEAR
(FSI)	AREA	(IN/IN)	DEFLECTION
	(IN*2)		(IN)
6807	288	0.0005101012	0.0010202023

ELEMENT # 4	RUBBER			
EA	DEPTH	TRANSVERSE		HEIGHT
(PSI)	B4	H4	L4	L3
	(IN)	(IN)	(IN*4)	(IN)
992	12	24	13824	6

12E414/L4*3	6E414/L4*2	4E414/L4	2E414/L4
7.6186E+05	2.2858E+06	9.1423E+06	4.5711E+06

RIGIDITY	TOP	SHEAR	ELEMENT	TOTAL
GIR	CONTACT	STRAIN	SHEAR	SHEAR
(FSI)	AREA	(IN/IN)	DEFLECTION	DEFLECTION
	(IN*2)		(IN)	(IN)
335	288	0.0103556924	0.0621341541	5.0951E-01

[illegible]

KNOWN VALUES:

Q1 = -1000 lbs  
M1 = Q1\*(L1+L2+L3+L4) = -75000 IN\*lbs  
Q2 = M2 = Q3 = M3 = M4 = Q4 = M5 0  
Q5 = 1000 lbs  
q1 = th1 = 0

# OF SYSTEM BLOCKS =

29

SOLVED UNKNOWNNS:

q2= 0.0000573372 in  
th2 0.0000020651 rad

q3 0.083548359 in

-B1 -B2  
-1006.01829834 -27062.032332

th3 0.007440467 rad

q4 0.084414111 in

-179512071.1 -164710050.6

th4 0.0074310941 rad

q5 0.1482973266 in

-90027.411451 -299112.21654

th5 0.0087626781 rad

K BEND HORIZ. FOR 1 SIDE BLOCK = 10158.4281952 lbs/in

10.1584281952 KIPS/IN

K BEND HORIZ. ALL SIDE BLOCKS = 294594.41766 lbs/in

294.59441766 KIPS/IN

MATRIX CHECK:

Q1 = -1000.0000  
M1 = -75000.0000  
Q2 = 0.0000  
M2 = 0.0000  
Q3 = 0.0000  
M3 = 0.0000  
Q4 = 0.0000  
M4 = 0.0000  
Q5 = 1000.0000  
M5 = 0.0000

TOTAL SIDE BLOCK HORIZONTAL STIFFNESS COEFFICIENT CALCULATION:  
SYSTEM B6 1" RUBBER CAP W/ ISOLATORS KU

KHS (SIDE BLOCK HORIZONTAL STIFFNESS) = P/(BENDING DISPL + SHEAR DISPLACEMENT)

Khs = 1.52 KIPS/IN (PER BLOCK)  
44.96  
Khs = 44.96 KIPS/IN (ENTIRE SIDE BLOCK SYSTEM)

# Required Isolator Characteristics Spreadsheet . . . . .

ISOLATOR REQUIREMENTS FOR SYSTEM B6:

TOTAL FOR KEEL ISOLATORS (55 BLOCKS):

Xe1 = 0.56756 IN  
KHX = 180 KIPS/IN  
KXHP = 26 KIPS/IN  
QD1 = 92.25 KIPS  
MAX R1 = 195 KIPS

DIMENSIONS: 42x48x29 INCHES  
EQUIVALENT REQ'D ISOLATOR KHX TOTAL= 144.72 KIPS/IN  
EQUIVALENT KHX PER ISOLATOR = 2.63 KIPS/IN  
EQUIVALENT REQ'D ISOLATOR KXHP TOT= 20.4 KIPS/IN  
EQUIVALENT KXHP PER ISOLATOR = 0.37 KIPS/IN  
KVK = 25286.68 KIPS/IN  
MAX R3 = 15200 KIPS  
EQUIVALENT REQ'D ISOLATOR KVK TOTAL= 1169 KIPS/IN  
EQUIVALENT KVK PER ISOLATOR = 21.25 KIPS/IN

TOTAL FOR ONE SIDE OF SIDE BLOCK ISOLATORS (29 BLOCKS):

Xe2 = 0.41939 IN  
KHS = 37 KIPS/IN  
KSHP = 6 KIPS/IN  
QD2 = 92.25 KIPS  
MAX R2 = 36 KIPS

DIMENSIONS: 24x20x20 INCHES  
EQUIVALENT REQ'D ISOLATOR KHS TOTAL= 59.71 KIPS/IN  
EQUIVALENT KHS PER ISOLATOR = 2.06 KIPS/IN  
EQUIVALENT REQ'D ISOLATOR KSHP TOT= 9.38 KIPS/IN  
EQUIVALENT KSHP PER ISOLATOR = 0.32 KIPS/IN  
KVS = 4554.23 KIPS/IN  
MAX R4 = 4275 KIPS

EQUIVALENT REQ'D ISOLATOR KVS TOTAL= 670.0 KIPS/IN  
EQUIVALENT KVS PER ISOLATOR = 23.10 KIPS/IN

## APPENDIX 6

1. "3DOFRUB" Wale Shore (EL Centro)  
Input Data File
2. "3DOFRUB" Wale Shore (EL Centro)  
Output File
3. "3DOFRUB" Wale Shore (NORM DD2)  
Output File
4. Wale Shore Design Spreadsheet

**"3DOFRUB" Wale Shore (EL Centro)  
Input Data File . . . . .**

\*\*\*SHIP/ELB DRYDOCK BLOCKING SYSTEM\*\*\* DATA FILE: P:SSIWS.DAT

\*\*\*INPUT FILE DATA\*\*\*

SHIP NAME: LAFAYETTE SSN 616  
DISCRPTION OF ISOLATORS IF USED: 1" RUBBER CAP  
DISCRPTION OF BUILDUP:  
8 FT SPACING COMPOSITE CAP AND PIERS RIGIDLY ATTACHED TO GROUND  
DISCRPTION OF WALE SHORES USED: WALE SHORE DESIGN  
DISCRPTION OF DAMPING: 5 % DAMPING  
LOCATION OF DRYDOCK BEING STUDIED: NO SPECIFIC LOCATION  
NAVSEA DOCKING DRAWING NUMBER: 845-2008640  
REFERENCE SPREADSHEET STIFFNESS CALC FILE NAME: SYSTEM 12  
MISC. COMMENTS: SSIWS.DAT 1955 15 FEB 88

SHIP WEIGHT (KIPS)	W= 16369.9
HEIGHT OF KG (IN)	H= 193
MOMENT OF INERTIA (KIPS*IN*SEC^2)	Ik= 2410451
SIDE PIER VERTICAL STIFFNESS (KIPS/IN)	Kvs= 4554.23
SIDE PIER VERTICAL PLASTIC STIFFNESS (KIPS/IN)	Kvsp= 7552.4
KEEL PIER VERTICAL STIFFNESS (KIPS/IN)	KVK= 25286.68
KEEL PIER VERTICAL PLASTIC STIFFNESS(KIPS/IN)	KVKP= 37857.79
HEIGHT OF WALE SHORES (IN)	AAA= 193
WALE SHORE STIFFNESS (KIPS/IN)	KS= 6000
SIDE PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHS= 4583.79
KEEL PIER HORIZONTAL STIFFNESS (KIPS/IN)	KHK= 18215.1
SIDE PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KSHP= 4583.79
KEEL PIER HORIZONTAL PLASTIC STIFFNESS(KIPS/IN)	KKHP= 18215.1
RESTORING FORCE AT 0 DEFLECT KEEL HORIZ (KIPS)	QD1= 0
RESTORING FORCE AT 0 DEFLECT SIDE HORIZ (KIPS)	QD2= 0
RESTORING FORCE AT 0 DEFLECT SIDE VERT (KIPS)	QD3=-545.44
RESTORING FORCE AT 0 DEFLECT KEEL VERT (KIPS)	QD4=-2734.11
GRAVITATIONAL CONSTANT (IN/SEC^2)	GRAV= 386.09

SIDE BLOCK WIDTH (IN)	SBW= 855
KEEL BLOCK WIDTH (IN)	KBW= 855
SIDE BLOCK HEIGHT (IN)	SBH= 75
KEEL BLOCK HEIGHT (IN)	KBH= 61
BLOCK ON BLOCK FRICTION COEFFICIENT	U1= 9
HULL ON BLOCK FRICTION COEFFICIENT	U2= .75
SIDE PIER TO SIDE PIER TRANSVERSE DISTANCE (IN)	BR= 144
SIDE PIER CAP PROPORTIONAL LIMIT	SCPL= .7
KEEL PIER CAP PROPORTIONAL LIMIT	KCPL= .7
TOTAL SIDE PIER CONTACT AREA (ONE SIDE) (IN^2)	SAREA= 8352
TOTAL KEEL PIER CONTACT AREA (IN^2)	KAREA= 55440
PERCENT CRITICAL DAMPING	ZETA= .05
HULL NUMBER (XXXX)	HULL= 616
SYSTEM NUMBER (XXX)	NSID= 01
CAP ANGLE (RAD)	BETA= .377

"3DOFRUB" Wale Shore (EL Centro)  
Output File . . . . .

\*\*\*\* System 51 \*\*\*\*

\*\* Hull 616 \*\*

\* Ship Parameters \*

Weight	Moment of Inertia	M.G.
16369.9 kips	2410451.0 kips-in-sec <sup>2</sup>	193.0 ins

\* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
75.0 ins	999.0 ins	61.0 ins	999.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
144.0 ins	193.0 ins	6000.0 kips/in	.377 rad
1Side Side Pier Contact Area	Total Keel Pier Contact Area	kkhp	
8352.0 in <sup>2</sup>	55440.0 in <sup>2</sup>	18215.1 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kshp	kvsp
.9000	.750	4583.8 kips/in	7552.4 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	kvkp	
.700 kips/in <sup>2</sup>	.700 kips/in <sup>2</sup>	37857.8 kips/in	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness		
4554.2 kips/in	4583.8 kips/in		
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness		
25298.7 kips/in	18215.1 kips/in		
DD1	DD2	DD3	DD4
.0 kips	.0 kips	-545.4 kips	-2734.1 kips

\* System Parameters and Inputs \*

Earthquake Used is 1940 EL CENTRO

Horizontal acceleration input is HORIZONTAL

Vertical acceleration input is  
Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio	Data Time Increment
1.000	.010 sec

Gravitational Constant	% System Damping
386.09 in/sec <sup>2</sup>	5.00 %

Mass Matrix

42.3992	.0000	8183.0420
.0000	42.3992	.0000
8183.0420	.0000	2410451.0000

Damping Matrix

112.6209	.0000	12864.9077
.0000	120.7612	.0000
12864.9077	.0000	3294384.8142



# Stiffness Matrix

```

59532.6200      .0000      2444346.1200
.0000      54295.1400      .0000
2444346.1200      .0000      490307122.3111
    
```

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	13.912 rad/sec	44.216 rad/sec	28.482 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	13.895 rad/sec	44.161 rad/sec	28.446 rad/sec

For Earthquake Acceleration of 100.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.130291			5.59
Maximum Y		-.252994		5.34
Maximum Rotation			-.004427	5.42
Side block sliding	.185743	.084169	-.004133	5.40
Side block overturning	.185743	.084169	-.004133	5.40
Side block liftoff	-.030776	.141339	.003411	5.22

For Earthquake Acceleration of 90.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.170186			5.59
Maximum Y		-.227635		5.34
Maximum Rotation			-.003984	5.42
Side block liftoff	.164073	.131310	-.003910	5.41

For Earthquake Acceleration of 80.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.150553			5.59
Maximum Y		-.203158		5.34
Maximum Rotation			-.003528	5.42
Side block liftoff	.130779	.153106	-.003528	5.42

For Earthquake Acceleration of 70.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.123083			5.59
Maximum Y		-.181906		5.34
Maximum Rotation			-.002984	5.42

No failures occurred.

For Earthquake Acceleration of 79.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.148859			5.59
Maximum Y		-.200619		5.34
Maximum Rotation			-.003483	5.42
Side block liftoff	.129196	.151192	-.003483	5.42

For Earthquake Acceleration of 78.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.148360			5.59
Maximum Y		-.198222		5.34
Maximum Rotation			-.003433	5.42
Side block liftoff	.127544	.149438	-.003433	5.42

For Earthquake Acceleration of 77.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.144471			5.59
Maximum Y		-.195681		5.34
Maximum Rotation			-.003389	5.42
Side block liftoff	.125900	.147522	-.003389	5.42

For Earthquake Acceleration of 76.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.141425			5.59
Maximum Y		-.193812		5.34
Maximum Rotation			-.003332	5.42
Side block liftoff	.124888	.146568	-.003332	5.42

For Earthquake Acceleration of 75.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.139552			5.59
Maximum Y		-.191262		5.34
Maximum Rotation			-.003288	5.42
Side block sliding	.123237	.144640	-.003288	5.42
Side block overturning	.123237	.144640	-.003288	5.42
Side block liftoff	.102642	.161626	-.003261	5.43

For Earthquake Acceleration of 74.00 % of the 1940 EL CENTRO

Maximum X	-.135798			5.59
Maximum Y		-.189456		5.34
Maximum Rotation			-.003212	5.42
Side block sliding	.078987	.180034	-.003086	5.44
Side block overturning	.078987	.180034	-.003086	5.44
Side block liftoff	.101108	.180146	-.003186	5.43

For Earthquake Acceleration of 73.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.134148			5.59
Maximum Y		-.187440		5.34
Maximum Rotation			-.003136	5.42
Side block sliding	.097464	.157809	-.003107	5.43
Side block overturning	.097464	.157809	-.003107	5.43

For Earthquake Acceleration of 72.00 % of the 1940 EL CENTRO

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	-.131683			5.59
Maximum Y		-.186486		5.34
Maximum Rotation			-.003082	5.42

No failures occurred.

"3DOFRUB" Wale Shore (NORM DD2)  
Output File . . . . .

\*\*\* System 51 \*\*\*

\*\* Hull 616 \*\*

\* Ship Parameters \*

Weight	Moment of Inertia	K.G.
16389.9 kips	2410451.0 kips-in-sec2	193.0 ins

\* Drydock Parameters \*

Side Block Height	Side Block Width	Keel Block Height	Keel Block Width
75.0 ins	999.0 ins	61.0 ins	999.0 ins
Side-to-Side Pier Distance	Wale Shore Ht.	Wale Shore Stiffness	Cap Angle
144.0 ins	193.0 ins	6000.0 kips/in	.377 rad
1Side Side Pier Contact Area	Total Keel Pier Contact Area	kthp	
8352.0 in2	55440.0 in2	18215.1 kips/in	
B/B Friction Coeff	H/B Friction Coeff	kshp	kvsp
.9000	.750	4583.8 kips/in	7552.4 kips/in
Side Pier Fail Stress Limit	Keel Pier Fail Stress Limit	kvkp	
.700 kips/in2	.700 kips/in2	37857.8 kips/in	
Side Pier Vertical Stiffness	Side Pier Horizontal Stiffness		
4554.2 kips/in	4583.8 kips/in		
Keel Pier Vertical Stiffness	Keel Pier Horizontal Stiffness		
25286.7 kips/in	18215.1 kips/in		
DD1	DD2	DD3	DD4
.0 kips	.0 kips	-545.4 kips	-2734.1 kips

\* System Parameters and Inputs \*

Earthquake Used is 1 OCT 87 WHITTIER \* 10.94

Horizontal acceleration input is LBNSY DD2 TRANSVERSE COMPONENT

Vertical acceleration input is LBNSY DD2 VERTICAL COMPONENT

Earthquake Acceleration Time History.

Vertical/Horizontal Ground Acceleration Ratio      Data Time Increment

1.000      .010 sec

Gravitational Constant      % System Damping

386.09 in/sec2      5.00 %

Mass Matrix

42.3992	.0000	8183.0420
.0000	42.3992	.0000
8183.0420	.0000	2410451.0000

Damping Matrix

112.6209	.0000	12864.9077
.0000	120.7612	.0000
12864.9077	.0000	3344384.8143

# Stiffness Matrix

39382.6800	.0000	24.0000
.0000	34395.1400	.0000
2444346.1200	.0000	43000.0000

Undamped Natural Frequencies	Mode #1	Mode #2	Mode #3
	13.912 rad/sec	44.210 rad/sec	28.490 rad/sec
Damped Natural Frequencies	Mode #1	Mode #2	Mode #3
	13.895 rad/sec	44.161 rad/sec	28.490 rad/sec

For Earthquake Acceleration of 100.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.146279			4.21
Maximum Y		.141489		4.44
Maximum Rotation			.006770	7.85
Side block sliding	-.106816	.018661	.005081	8.37
Side block overturning	-.106816	.018661	.005081	8.37
Side block liftoff	.101835	.008066	-.005242	7.57
Side block crushing	-.126764	.018346	.006770	7.85

For Earthquake Acceleration of 90.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.132140			4.21
Maximum Y		.127431		4.44
Maximum Rotation			.006075	7.85
Side block sliding	.110379	.017975	-.005054	7.59
Side block overturning	.110379	.017975	-.005054	7.59
Side block liftoff	.109161	.021440	-.005097	7.60

For Earthquake Acceleration of 80.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.118111			4.21
Maximum Y		.113385		4.44
Maximum Rotation			.005349	7.85
Side block sliding	-.099814	.024784	.004983	7.82
Side block overturning	-.099814	.024784	.004983	7.82
Side block liftoff	-.102703	.023521	.005192	7.83

For Earthquake Acceleration of 70.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.103739			4.21
Maximum Y		.099230		4.44

No failures occurred.

For Earthquake Acceleration of 79.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.116810			4.21
Maximum Y		.111976		4.44
Maximum Rotation			.005283	7.85
Side block sliding	-.099938	.007420	.005284	7.86
Side block overturning	-.099938	.007420	.005234	7.86
Side block liftoff	-.101425	.023417	.005127	7.86

For Earthquake Acceleration of 78.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.115422			4.21
Maximum Y		.110565		4.44
Maximum Rotation			.005216	7.85
Side block liftoff	-.100145	.022933	.005062	7.83

For Earthquake Acceleration of 77.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.114073			4.21
Maximum Y		.109152		4.44
Maximum Rotation			.005150	7.85
Side block sliding	-.098869	.022639	.004997	7.83
Side block overturning	-.098869	.022639	.004997	7.83
Side block liftoff	-.099086	.013273	.005115	7.84

For Earthquake Acceleration of 76.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.112592			4.21
Maximum Y		.107735		4.44
Maximum Rotation			.005051	7.85
Side block sliding	-.097927	.019054	.005051	7.84
Side block overturning	-.097927	.019054	.005051	7.84

For Earthquake Acceleration of 75.00 % of the 1 OCT 87 WHITTIER \* 10.94

Maximums/Failures	X (ins)	Y (ins)	Theta (rads)	Time (sec)
Maximum X	.111111			4.21
Maximum Y		.106317		4.44

No failures occurred.

## Wale Shore Design Spreadsheet

VERTICAL STIFFNESS CALCULATIONS FOR WALE SHORES

WALL TYPE = 006 DOCKING PLAN # = 040-000000

SYSTEM # 51 WALE SHORES ORIGINAL DOCKING DRAWING  
 BLOCK SPA 8.00 FEET RUBBER CAP E2  
 LBNSY DD2  
 27X14 WF 42.68

VERTICAL STIFFNESS:

LEVEL	MATERIAL	E (PSI)	LENGTH (IN)	WIDTH (IN)	HEIGHT (IN)	K (KIPS/IN)	1/K	PIER TOTAL K (KIPS/IN)
			(DEPTH)	(TRANSVERSE)				
			(D)	(H)	(L)			
1	RUBBER	3571	29.00	17.00	1.00	1760.50	0.0005680	437.51
2	RUBBER	3571	29.00	17.00	2.50	704.20	0.0014200	
3	STEEL	30000000	29.00	17.00	0.50	29580000.00	0.0000000	
4	STEEL	30000000	1.00	42.68	381.00	3360.63	0.0002976	
						385.00		
					#			
					WALE SHORES			
					14			
					IN <sup>2</sup>			